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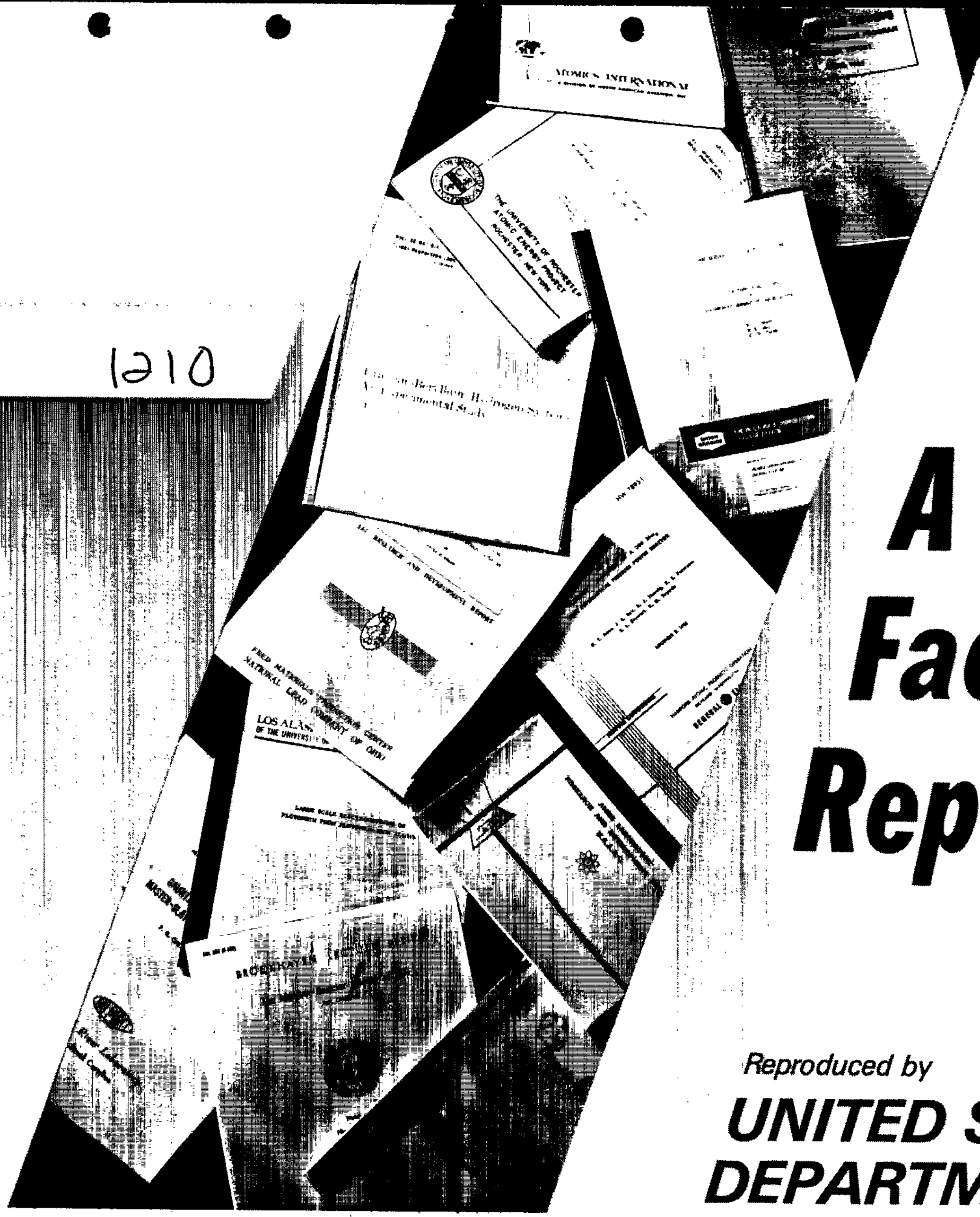

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UNITED STATES ATOMIC ENERGY COMMISSION

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GEOLOGIC CONDITIONS AT THE OAK RIDGE NATIONAL LABORATORY (X-10) AREA RELEVANT TO THE DISPOSAL OF RADIOACTIVE WASTE

By
Paris B. Stockdale

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William A. Strauser
Chief, Declassification Branch

August 1, 1951

University of Tennessee

Technical Information Service, Oak Ridge, Tennessee

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GEOLOGIC CONDITIONS AT THE OAK RIDGE NATIONAL LABORATORY (X-10) AREA RELEVANT TO THE DISPOSAL OF RADIOACTIVE WASTE

By

Paris B. Stockdale

(With A Special Chapter on Hydrologic Features by George D. DeBuchananne, and with Geologic Maps by Harry J. Klepser)

CONTENTS

TABLES

Plates inserted following page 87

Plates 3 - 10 are omitted from this compilation. These are detailed geologic maps of various portions of the Oak Ridge National Laboratory area. These portions are all included in plate 2. The detailed maps may be examined in the files of the U. S. Atomic Energy Commission Technical Information Service, Oak Ridge, Tennessee.

FOREWORD
(By Edward McCrady)*

For the past three years the Oak Ridge Office of the Atomic Energy Commission has been conducting a geological survey of the Oak Ridge area with several purposes in mind. It was desired to know: (1) the general stratigraphy as a basis for architectural and engineering considerations relative to foundations for buildings; (2) the ground water conditions both as they affect the choice of sites for burial grounds for solid radioactive wastes, and as they are related to the radioactive liquid waste disposal system.

The work has been done under the general direction of Dr. Paris B. Stockdale of the University of Tennessee, acting as Geological Consultant to the Biology Division of the Office of Research and Medicine, Atomic Energy Commission, Oak Ridge, assisted by Dr. Harry J. Klepser of the University of Tennessee and Mr. George D. DeBuchananne of the Ground Waters Branch of the U. S. Geological Survey. The investigations originally planned are now completed and the report herewith presented includes important information relative to all the original interests of the Commission.

Actual operations have already been affected to the extent that the locations of two new reactor sites and certain other structures have been selected on the basis of information supplied by Dr. Stockdale, and the new burial ground has been located in the Conasauga shale belt where geological conditions are considered optimal for preventing the migration of radioactive wastes underground.

The study of the underground water in relation to the liquid waste

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disposal system at the X-10 site of the Oak Ridge National Laboratory is the most recent part of the program to arrive at definite and useful conclusions. In this connection the most important question to be settled was whether artesian or water-table conditions prevail underground. It was known that the bed rock of this valley is predominantly limestone of the Chickamauga group; and in the absence of definite information to the contrary it would be quite possible for this limestone to be traversed by solution channels, which could be independent of the surface drainage, and might run for miles underground, even conceivably passing beneath the Clinch River to emerge in springs which might be used by people for drinking purposes.

Accordingly it was very important to find out, if possible, whether such voids exist, and whether and to what extent any water found in them is contaminated with fission products from the liquid waste disposal system. To investigate this, fifty one wells were drilled totalling 4500 feet. Cores were removed and saved for geological and chemical study, and the water in the wells was monitored for radioactivity as well as chemically analysed. It was also realized that no matter how many wells were drilled, if artesian conditions existed in which the underground channels or aquifers were independent of one another and of the surface, we could never know positively that we had sampled them all.

Fortunately, what was actually found was that the rock is sufficiently fractured and jointed to provide water-table conditions in which the level of the water underground follows quite closely the contours of the surface topography, with the result that underground drainage parallels the surface drainage with reasonable accuracy. The lay of the land is such that all drainage at and below the surface converges to empty through the intended liquid waste disposal system of Whiteoak Creek and Whiteoak Lake. That portion of the water which goes underground is merely held up longer and allowed to decay further before final discharge. The only contamination of underground water actually found is confined to a very restricted area near the known sources, and is of a lower degree than that of the surface stream. Apparently the soil has acted as a filter, or adsorber, or ion-exchange bed, which has to a considerable degree decontaminated the water which passed through it. As even the surface water is sufficiently held up and diluted to be safe for human consumption by the time it reaches the Clinch River, it may be confidently stated that the system as a whole is remarkably successful, and more efficient than was heretofore known.

Chapter I. INTRODUCTION

HISTORICAL BACKGROUND TO THE STUDY

The writer's attention was first called to the problem involved in this study by a letter, under date of March 22, 1948, from Dr. Albert H. Holland, Jr., Medical Advisor to the U. S. Atomic Energy Commission at Oak Ridge, inviting him to make a "detailed geological survey" in connection with "a study of radioactive liquid waste disposal at Oak Ridge" under the sponsorship of the Office of Medical Advisor (now reorganized as the Office of Research and Medicine). It was explained that several persons and agencies representing the Atomic Energy Commission, the U. S. Public Health Service, the Tennessee Valley Authority, the Oak Ridge National Laboratory, and others, would cooperate in the study. Although since that time intermittent services in connection with a wide variety of matters have been rendered by Stockdale to the Atomic Energy Commission, the principal efforts have been directed toward study of geologic conditions bearing upon contamination from disposal of radioactive waste at the X-10 unit of the Oak Ridge National Laboratory, especially as related to the potential contamination of migrating underground waters. (For location, see Plate 1.) It soon became apparent that the geologic studies most needed were those of combined bed-rock geology (stratigraphy and structure) and hydrology.

Field studies were started by Stockdale on June 23, 1948, with a general geologic reconnaissance of "the Oak Ridge Area." But little work was done in the summer of 1948. However, during the autumn of 1948 and early winter of 1949, Stockdale, working alone, completed the general geologic survey and established pertinent facts in detail about the stratigraphy and structure at the X-10 site of the Oak Ridge National Laboratory and surrounding area.

A field conference on the general problem was held at Oak Ridge on March 24, 1949. Those present were:

A. E. Gorman, Sanitary Engineer, Atomic Energy Commission, Washington

J. A. Lieberman, Assistant Sanitary Engineer, Atomic Energy Commission, Washington

Edward McCrady, Senior Biologist, Office of Research and Medicine Atomic Energy Commission, Oak Ridge

Paris B. Stockdale, Head of the Department of Geology and Geography, University of Tennessee, Knoxville

The many aspects of the contamination problem were reviewed in the field, and the geologic factors and proposed method of study were pointed out by Stockdale. At that time Stockdale also expressed need for assistance in the work and invited opinions regarding his proposed second and third "phases" in the program, to follow the initial reconnaissance survey; namely, detailed geologic mapping of the Oak Ridge National Laboratory area (second stage in the study), and systemmatic core drilling for the combined benefits of the bedrock and hydrologic studies (third stage in the study). At that time, it was decided to hold a later field conference which might bring A. M. Piper, Staff Scientist, U. S. Geological Survey and A. N. Sayre, Chief of the Ground Water Branch of the Water Resources Division, U. S. Geological Survey, for the pooling of opinions and possibly arranging for field assistance in the hydrologic aspects of the study. Such a conference was held at Oak Ridge on June 23, 1949, following. In the meantime, the overall aspects of the problem were discussed by Stockdale with R. A. Laurence, Director of the regional office of the Geologic Division of the U. S. Geological Survey in Knoxville, and on May 26, 1949, a day was spent in the field with Laurence with especial consideration of a new site recommended by Stockdale for storage or burial of solid radioactive waste and contaminated items.

In June 1949, Harry J. Klepser, Associate Professor of Geology at the University of Tennessee, was employed as a consultant by the Atomic Energy Commission at Oak Ridge to assist in the study, especially in the detailed geologic mapping involved in the second phase of the program. The field mapping was then pursued by him during a portion of the ensuing summer. He also assisted in various ways in later phases of the study, and is responsible for the preparation of the geologic maps and structure section in this report.

At the conference mentioned above, on June 23, 1949, the following persons were present:

A. E. Gorman, Sanitary Engineer, Atomic Energy Commission, Washington

J. A. Lieberman, Assistant Sanitary Engineer, Atomic Energy Commission, Washington

Harry Stoeckle, Chief of the Biology and Medicine Division, Atomic Energy Commission, Oak Ridge

R. A. Laurence, Regional Geologist, U. S. Geological Survey, Knoxville

A. M. Piper, Staff Scientist, U. S. Geological Survey, Washington

A. N. Sayre, Chief of the Ground Water Branch, U. S. Geological Survey, Washington

Paris B. Stockdale, Head of the Department of Geology-Geography, University of Tennessee, Knoxville

In the group conference which followed a field excursion, concurrence was given to the three-phase program of study as proposed by Stockdale, and agreement was reached for collaboration of personnel from the Ground Water Branch of the U. S. Geological Survey to work, especially, on the hydrologic aspects of the geological survey as involving water-table conditions and movements of ground water. Sayre stated that, logically, it would be most appropriate to assign to the project George D. DeBuchananne who was in charge of the Knoxville office of the Ground Water Branch of the Survey. However, it was pointed out that inasmuch as DeBuchananne did not have appropriate security clearance, a substitute person could be temporarily assigned for work until such time as DeBuchananne could be "cleared," and that the substitute should devote his efforts toward making a surface appraisal of ground-water features, to be completed no later than September 30, 1949. A typed memorandum of this conference was prepared by Piper under date of June 25, 1949. The person assigned temporarily from the Ground Water Branch of the U. S. Geological Survey to make the proposed inventory of ground-water features and available hydrologic data was E. S. Simpson from Albany, N. Y., who arrived at Oak Ridge on July 25, 1949. He spent his first day in the field with Stockdale getting acquainted with the problem in general. His work was completed by the expressed date and results of his studies were transmitted direct to the Ground Water Branch of the U. S. Geological Survey.

In anticipation of the next, or third, major phase of the study, a planning conference was held in Oak Ridge on September 21, 1949.

Present were:

Edward McCrady, Chief, Biology Division, Office of Research and Medicine, Atomic Energy Commission, Oak Ridge

R. A. Laurence, Regional Geologist, U. S. Geological Survey, Knoxville

E. S. Simpson, Ground Water Branch, U. S. Geological Survey, Albany, N.Y.

Harry J. Klepser, Associate Professor, Department of Geology-Geography, University of Tennessee, Knoxville

Paris B. Stockdale, Head of the Department of Geology-Geography, University of Tennessee, Knoxville

At this conference final plans for the next stage in the study were reviewed and agreed upon, and the general scope for the proposed core-drilling project was drawn.

George D. DeBuchananne of the Knoxville office of the Ground Water Branch, U. S. Geological Survey, began his work on the program on November 4, 1949. Core drilling started on December 16, 1949, and was completed on March 22, 1950. Fifty-one holes, totalling 4500 feet, were drilled. From the time drilling commenced to date, DeBuchananne, Klepser, and Stockdale, along with personnel from the Health Physics Division of the Oak Ridge National Laboratory, have been intermittently engaged in the study, involving planning and supervision of drilling, logging of core, sampling, obtaining hydrologic data, analyzing samples, etc. The ground-water study has been the chief responsibility of DeBuchananne; the detailed field mapping, of Klepser; and the general stratigraphy and structure, the overall direction of the study, and the preparation of this report, of Stockdale. The entire program has been under the sponsorship and guidance of the Biology Division, Office of Research and Medicine, of the U. S. Atomic Energy Commission, at Oak Ridge, Edward McCrady, Chief.

FUNDAMENTAL PROBLEM AND OBJECTIVES OF THE STUDY

General Statement

The chief concerns of this study were the geologic and ground-water features as critical factors in the over-all problem of safety discharging radioactive waste products from the operations at the X-10 unit of the Oak Ridge National Laboratory of the U. S. Atomic Energy Commission, Oak Ridge, Tennessee. It is not the intent of this report to analyze the waste problem completely and finally, but rather to undertake a coverage in detail of those features of geology and ground water, as a basis for a fuller evaluation and understanding of the disposal problem and for better guidance of future investigations and operations. The study leads to some immediate recommendation and paves the way for further investigations pertinent to complete understanding of the problem. There has been no prior geologic study bearing directly upon the problem of waste disposal at Oak Ridge.

Waste Disposal System at the Oak Ridge National Laboratory (X-10)

Safe disposal of liquid radioactive wastes, as well as solid wastes and contaminated materials and equipment, at the X-10 unit of the Oak Ridge National Laboratory, has been a problem of paramount importance since the beginning of operations. Disposal of solid wastes and contaminated equipment is by burial in the ground. Alpha-contaminated materials are first covered with concrete before burial. It is liquid waste disposal at the Laboratory which presents the greatest problem. To understand its bearing upon the geologic factors involved, a brief description of the complicated disposal system is here offered. The information has been extracted mainly from a technical report by

F. N. Browder, entitled "Liquid Waste Disposal at Oak Ridge National Laboratory," ORNL 328, issued May 17, 1949, and in part from later reports by Browder.

Liquid wastes from Oak Ridge National Laboratory processes are classified into four types according to composition and radioactivity, namely: (a) radiochemical waste, which is highly radioactive and which comes from special "hot" sinks and vessels in cells devoted to "hot" work; (b) metal waste, which is highly radioactive plutonium, uranium, or thorium-bearing waste; (c) warm radiochemical waste, which is moderately radioactive; and (d) process waste, theoretically non-radioactive, which is derived from cooling water, laboratory sinks, and floor drains.

The liquid waste disposal system, as described by Browder, is divided into three main sections, namely: (a) the north tank farm, containing two 4400-gallon, and two 40,000-gallon gunite tanks; (b) the south tank farm, containing six 170,000-gallon gunite tanks, one 1300-gallon gunite tank, and one 700-gallon stainless steel tank; and (c) the settling basin area, containing four earthen-diked ponds, the main one of which is approximately 200 feet square with a capacity of 1,600,000 gallons, two with capacity of 293,200 gallons each, and one, known as the retention pond, of 32,600 gallons. (For locations, see Plate 2.) All of the tanks in the two tank farms are below ground level and are earth covered. All rest upon a concrete saucer-shaped pad to catch any leakage which in turn drains into a "dry well," and thence, through a pipe line, into the retention pond of the basin area. In addition to the main system, described above, there are smaller waste tanks and pits located near the various process and development buildings. Specific details are given by Browder.

The function of the two tank farms is to collect and store metal waste and to collect and hold radiochemical waste over a period of time long enough for sufficient decay. From the tank farms the decayed radiochemical waste is discharged into the main settling pond where it is diluted with sufficient quantities of non-radioactive waste to permit discharge into adjacent Whiteoak Creek at a rate not exceeding five curies of radioactivity per week, with an average of about 2.34 curies per week as of June, 1950. Intermittently, however, excess waste is dumped into the smaller, 293,000-gallon ponds before being run into the main settling pond. The several lesser tanks near the process and development buildings serve as intermediate hold-up before the fluids are sent to the main tank farms. The diluted wastes which are discharged from the settling ponds into Whiteoak Creek are carried downstream for a distance of approximately one mile to Whiteoak Lake for the final hold-up of the disposal system before discharge into the Clinch River. In early June of 1949, the disposal system was modified by the installation of an evaporation system to permit the radiochemical wastes to be concentrated for longer retention in the tank farms.

Potential Hazards Involved in the Disposal System

The settling ponds, described above, were constructed simply by scooping up the soil down to bedrock and using the soil to make the enclosing earthen dikes. The principal pond, often referred to as "the settling basin," is nearly square in outline, with bottom dimensions of 190 by 200 feet. The others are much smaller. There was no provision made to seal the bottom and walls of the ponds to prevent seepage and contamination underground. Likewise, at the burial grounds, the solid wastes and contaminated items are placed directly upon bedrock without protection against contaminated drainage underground. Thus, there exists the possibility of radioactive contamination of underground waters and the uncontrolled migration of such to unknown distant sites, providing there exist permissible geologic conditions beneath the potential sources of contamination. Greatest risk is beneath the settling ponds, especially the large one; less risk, beneath the bed of Whiteoak Creek adjacent to the ponds; and further risk, at the burial grounds. Additional risk would result, of course, from spills of liquid wastes through breaks in tanks and pipe lines.

Principal Objectives of the Study

The principal objectives of the study were: to obtain as much information as possible on geologic and ground-water conditions which bear or may bear upon potential hazards from waste-disposal practices at the X-10 unit of the Oak Ridge National Laboratory; to determine whether or not there now exists any radioactive contamination which has migrated underground; to determine the form of the water table and the movement of ground waters as potential carriers of radioactive contamination; to propose recommendations in light of findings; and, finally, to bring together into a single report all pertinent information bearing upon the problem. A further objective was to determine the geologic conditions, as regards both stratigraphy and structure, as a basis for architectural and engineering considerations relative to foundations for buildings and to other structures.

PERSONNEL AND ACKNOWLEDGMENTS

The direct interests of the U. S. Atomic Energy Commission in the collaborative program here reported were represented by Edward McCrady, Chief of the Biology Division of the Office of Research and Medicine at Oak Ridge, who rendered invaluable assistance and guidance. George D. DeBuchananne of the Knoxville office of the Ground Water Branch of the U. S. Geological Survey was chiefly responsible for the ground-water studies and for the preparation of Chapter V of this report. Harry J. Klepser, Professor of Geology at the University of Tennessee, did the detailed field mapping of the areal geology and prepared the geologic maps and structure section in this report. The overall direction of the study was the responsibility of Stockdale, author of this report, who acknowledges with thanks the splendid cooperation of the principal participants named above.

In addition to personnel who had direct responsibility toward the project, as above indicated, acknowledgments and thanks are due to numerous other individuals and agencies that rendered invaluable assistance of various sorts. Reference is made especially to the Health Physics Division of the Oak Ridge National Laboratory, K. Z. Morgan, Director, and F. Western, Associate Director. Thanks are also due J. C. Hart, in charge of the Area Monitoring Unit of the Division, and his associates, and to R. J. Morton of the Radioactive Waste Disposal Unit of the Division. Specific reference to other indivuduals who participated actively in special laboratory and field studies is made at appropriate places in the text of this report.

CHAPTER II. LOCATION AND PHYSIOGRAPHY

LOCATION OF THE AREA

The site of the X-10 unit of the Oak Ridge National Laboratory is in Bethel Valley, Roane County, eastern Tennessee. In terms of latitude and longitude the approximate center of the site is located at 35° 55' 30" north latitude and 84° 19' west longitude. It is eight and one half airline miles south-southwest of Jackson Square in the heart of the City of Oak Ridge, and 21½ miles west-southwest of the central business section of the city of Knoxville. The site is covered by the Tennessee Valley Authority-U.S. Geological Survey topographic map of the Bethel Valley Quadrangle, designated as No. 130-NE, published in 1941. (See Plate 1.) The scale of this map is 1/24,000 and the contour interval, 20 feet. A series of topographic sheets drawn to the scale of 1 inch to 100 feet with a contour interval of 5 feet was issued by Stone & Webster Engineering Corporation under date of June 4, 1943. The sectional sheets of this series which involve the laboratory site and immediately adjoining areas are Nos. B2-22, B2-23, B2-24, B2-25, B2-27, B2-28, B2-29, B2-30. (See Plates 3,4,5,6,7,8,9, and 10.) These large-scale sectional sheets are subdivisions of "Topographic Map-Section B-2", scale 1 inch to 400 feet, contour interval 10 feet, issued under date of October 31, 1942. (See Plate 2.)

TOPOGRAPHY AND DRAINAGE

Bethel Valley, in which the X-10 unit of the Laboratory is located, is not a simple stream valley in the ordinary sense. Instead, it is a portion of an elongated, northeast-southwest trending trough drained by several small streams tributary to the Clinch River. It has been developed upon a belt of non-resistant limestones and shaley limestones of the Chickamauga formation, striking north 56° east. The trough is bounded on the southeast by Haw Ridge, a narrow, dissected hogback held up by resistant sandstone of the Rome formation, and on the opposite side by Chestnut Ridge which is developed on the cherty dolomite of the Knox formation. The trough and its bounding parallel ridges extends northeastward from Bethel Valley into Raccoon Valley. The length of the Bethel Valley portion of the trough is seven and one half miles. The floor of the trough has an average width of about 1000 feet.

The part of Bethel Valley which holds the site of the Laboratory is drained by Whiteoak Creek and its tributaries. Just south of the Laboratory this stream flows out of Bethel Valley thru a narrow water gap which has been cut across Haw Ridge. From this gap the stream flows south-southwestward along another trough, developed in the soft shales of the Conasauga formation, to the Clinch River two miles away at an elevation of 741 feet. Approximately one half mile upstream from the mouth of Whiteoak Creek at the Clinch River, at the highway which leads to the White Wing Gate, there is an earth dam with steel cofferdam and gate (elevation 750 feet at top) which holds back a shallow water reservoir known as Whiteoak Lake. This serves as a final settling basin for liquid waste products which are discharged from operations at the Laboratory. (See Plate 1.)

The lowest elevation of Bethel Valley floor within the Laboratory area is where Whiteoak Creek passes thru Haw Gap at 770 feet. From here the floor rises to the west, north, and northeast. Whiteoak Creek is at an elevation of 800 feet one mile upstream (northeast) of the gap. On the northwest side of the valley floor there is a belt of elongated knolls which rise to elevations up to 900 feet. Some of the Laboratory plant operations are located on these knolls; others on their slopes and on the valley floor to the southeast. Highest points on Haw Ridge southeast of the Laboratory site reach above 1,040 feet in elevation, whereas points on Chestnut Ridge to the northwest range in elevation from 1,100 to over 1,200 feet. (See Plate 1.)

PHYSIOGRAPHIC SETTING

With respect to physiographic location, Bethel Valley lies in the midst of the Tennessee Section of the Valley and Ridge Province, a subdivision of the Appalachian Highlands Division. The Valley and Ridge Province, sometimes referred to as the "newer Appalachians" is characterized by alternating elongated and parallel valley-troughs and ridges, trending northeast-southwest in general accordance with the strike of the underlying rock strata which are of Paleozoic age. The valleys have been developed in the belts of non-resistant rock, whereas the ridges occupy sites of resistant strata. These belts, in turn, reflect the underlying structure of parallel folds and thrust faults.

The Valley and Ridge Province is bounded on the northwest by the Appalachian Plateaus Province (Cumberland Plateau in Tennessee) and on the southeast by the Blue Ridge Province which contains the highest mountains of the Appalachian system. The southeast edge of the Cumberland Plateau is but nine miles to the northwest of Bethel Valley, whereas the Blue Ridge Province is some 35 miles distant at its closest point to the southeast. The Great Smoky Mountains lie within the Blue Ridge Province.

Across the Oak Ridge "area" the succession of alternating ridges and valleys, in order from southeast to northwest, is as follows: Copper Ridge, Melton Valley, Haw Ridge, Bethel Valley, Chestnut Ridge, Bear Creek Valley, Pine Ridge, Gamble Valley, East Fork Ridge, East Fork Valley, and Black Oak Ridge. Each of the ridges attains elevations of over 1200 feet at their highest points, whereas the valley bottoms range in elevation from 741 feet at the Clinch River to over 900 feet. (See Plate 1.) The Oak Ridge townsite lies upon East Fork Valley and the adjacent Black Oak Ridge to the northwest, from which the town name was taken.

CHAPTER III. AREAL GEOLOGY

GENERAL STATEMENT

The geology of the region which embraces the Oak Ridge area has been mapped and described in a general way in two folios of the Geologic Atlas of the United States Geological Survey, namely, the Loudon Folio, No. 25, by Arthur Keith, published in 1896, and the Briceville Folio, No. 33, also by Arthur Keith, 1897. These well-known folios covering 30-minute quadrangles includes reconnaissance topographic sheets and geologic maps on the small scale of 1/125,000 (one inch to about two miles) with contour interval of 100 feet. The studies were highly generalized and were necessarily devoid of accurate details. Most of the town of Oak Ridge lies in the southern part of the Briceville Quadrangle, whereas the several plant operations of the U. S. Atomic Energy Commission, including the Oak Ridge National Laboratory, are within the northwestern portion of the Loudon Quadrangle.

STRATIGRAPHY

All of the bedrock formations of the Oak Ridge area are of sedimentary origin, deposited during the Paleozoic Era of geologic time. More specifically, they range in age from middle Cambrian to early Mississippian. The grouping and classification of the stratigraphic units is shown in Plate 11. The strata which underlie the site of the X-10 unit of the Oak Ridge National Laboratory in Bethel Valley belong to the Chickamauga group; those which uphold Haw Ridge to the southeast, to the Rome formation; those which underlie Melton Valley adjacent to Haw Ridge on the southeast, to the Conasauga group; and those which form Chestnut

Ridge at the northwest side of Bethel Valley, to the Knox group. The strata which are most pertinent to this study are those which lie underneath the immediate sources of radioactive contamination at the Oak Ridge National Laboratory operations and beneath Whiteoak Creek into which radioactive wastes are drained; namely, the Chickamauga limestones which are of greatest importance, the Rome sandstone and shale, and the Conasauga shale. The areal distribution and the structural arrangement of these geologic formations are shown on Plates 2 and 12. Since, as previously stated, the problem of fundamental concern in this study is the possible migration in various directions underground of radioactive fluid wastes or of other contaminated waters, it is important to understand the physical properties, especially the permeability, of the geologic formations in three-dimensional distribution. Therefore, this calls for accurate understanding of both the surface distribution of the geologic formations and the attitude and arrangement of the strata (geologic structure) with depth.

Throughout the Oak Ridge area the several geological formations, which are in sedimentary layers, crop out along parallel belts trending northeast-southwest. As previously indicated, these belts conform with the valley and ridge topography. The direction of strike is nearly constant throughout the area -- average, north 56° east. A slight departure from this average is noted from place to place. Nearly everywhere in the area the formations dip toward the southeast. The most common angle of dip is between 30 and 40 degrees with occasional variation in considerable amount at some localities. In the following paragraphs description of the several formations will be treated in the order of ascending succession of the rocks -- older to younger. Only those immediately involved in the problem of this paper have been studied in much detail.

Rome Formation

The Rome formation, of middle Cambrian age, consists mainly of evenly-bedded, fine-grained sandstone and shale. A striking characteristic is the variegated banding of brilliant shades of maroon, red, greenish-blue, olive-green, yellow, brown, gray, and drab. In some sections in the upper portion of the formation there occur massive, dark gray, dolomite lenses which are non-persistent. In the area of this study, the bulk of the formation is soft, slightly silty, argillaceous shale, containing scattered, thin siltstone layers less than an inch thick. The upper 150 feet or so of the formations contains most of the Rome sandstone (siltstone) which prevails in comparatively thin, but resistant layers up to three or four feet thick, separated by shale partings. At places these sandstone beds havebeen altered virtually to a quartzite. Primary features such as ripple marks, rill marks, and others, characterize the bedding surfaces of the sandy layers. In the Oak Ridge area, the sandstone portion of the Rome does not contain layers which are nearly as massive as in other eastern Tennessee regions. Nevertheless they are sufficiently resistant to erosion to have caused the development of prominent hog-back ridges, such as Haw Ridge and Pine Ridge. Above the sandstones of the Rome is a zone of drab-colored, sandy shale and shaly siltstone which grades upward into the typical shale of the overlying Conasauga formation. The thickness of the Rome formation is undetermined. Nowhere in the area of this study is the base of the

Rome formation exposed; everywhere it is underground at unknown depth. Enough of the formation is above cover, however, to indicate a thickness in excess of 1000 feet. Near the X-10 unit of the Oak Ridge National Laboratory, a good exposure of the Rome formation occurs in the road cuts where the highway leading to White Wing Gate crosses Haw Ridge. At this place the Rome is thrust-faulted against the Chickamauga strata to the northwest. A more complete section of the Rome formation is exposed along the highway at Bear Creek Gap, thru Pine Ridge, about one and three fourths miles northwest of the Laboratory.

Conasauga Group

This rock unit is mainly shale, mostly drab to olive-gray in color, with considerable reddish-brown to black stain. Although it is somewhat variegated in places, it does not possess the color brilliance which typifies the Rome rocks beneath. In the main the shale is argillaceous to slightly silty with some parts slightly calcareous. The shale tends to weather to a flaky appearance. Thruout there occur in varying quantities at different horizons thin siltstone layers, generally less than one inch thick, which stand out as ribs on weathered slopes and which disintegrate into small angular blocks. The basal portion of the Conasauga shale has been referred to by Rodgers as the Pumpkin Valley formation. Not far above the base of the Conasauga, and on top of the Pumpkin Valley unit, is a zone with a super abundance of siltstone ribs, sufficient in resistance to account for a line of low hills, or knolls, which rise above the valley floors carved in the softer shales. Such is exhibited along the northwest side of Bear Creek Valley, and along the northwest side of Melton Valley between Haw Ridge and Copper Ridge. The shale is highly impervious. There occur in the upper 200 feet or more of the Conasauga group beds of gray limestone of various textures and thicknesses separated by shale zones. Some are dense; some coarsely crystalline; some oolitic in texture. Many of the limestone beds are but a few inches thick; others are massive, up to several feet thick. This limestone portion of the Conasauga group is known as the Maynardville limestone. Detailed studies and measurements of sections were not made by the writer. The total thickness of the Conasauga, in the Oak Ridge area, is at least 1500 feet. Excellent exposures of both the shale and limestone units occur at many places in Bear Creek Valley, and along the highway to the White Wing Gate between Haw Ridge and Copper Ridge south of the X-10 unit of Oak Ridge National Laboratory.

Knox Group

Next above the Conasauga unit lies the Knox group, composed mainly of light to dark gray, dolomitic limestone with prominent chert zones. It is of late Cambrian and early Ordovician age. This group, which is often spoken of as the "Knox dolomite," is one of the most widely distributed stratigraphic units in east Tennessee. Bedrock exposures are sparse since nearly everywhere the rock is deeply weathered, leaving a deep cover of whitish to red residual, clayey soil characterized by abundant nodules and chunks of chert. Because of the preponderance of chert a hilly or ridge topography is generally developed. Underground solution channels, many of cavern proportions, characterize the Knox. Numerous large sink holes give further testimony to the role of solution and underground drainage in this calcareous group. Since detailed studies of the Knox in the Oak Ridge area have not been made, the five-fold subdivision which has been established for the group in areas farther northeast has not been determined. Such is not important in this study, however, since the Knox formations are not relevant to the immediate problem. The stratigraphic boundaries of the Knox group are easily determined because of the sharp lithologic contrasts with the Maynardville limestone of the Conasauga group at the base and with the limestones and shales of the Chickamauga group at the top. One of the best-exposed sections of the Knox, in the Oak Ridge area, is along the new Knoxville-Oak Ridge highway across Chestnut ridge, two miles south-southeast of Jackson Square in the town of Oak Ridge. In this section the Knox group is 2600 feet thick.

Chickamauga Group

The rocks of greatest concern in this study are those of the Chickamauga group which is comprised mainly of limestone beds. They are the ones which lie beneath the X-10 plant site of the Oak Ridge National Laboratory -- the ones which underlie the settling pond or holding basin, enclosed by earth-dikes, into which are discharged fluid wastes from the X-10 aircooled pile, the hot pilot plant, and other operations, and which also underlie the original burial grounds for burial of solid wastes and contaminated materials and discarded equipment. Furthermore, Whiteoak Creek flows over these rocks for a distance of approximately 1700 feet from the point where it receives the discharge of radioactive effluent from the settling pond to where it crosses the fault against the Rome formation in the water gap at Haw Ridge. (See Plates 1 and 2.) Since limestone may be susceptible to underground solution by migrating ground waters, with consequent development of a network of open channels and voids, often permitting easy access of surface waters and free movement of waters underground, the rocks of the Chickamauga group were of especial concern because of their potential "vulnerability" with respect to movement and escape of contaminated waters underground. Detailed studies and mapping were made, therefore, of the Chickamauga units.

The Chickamauga group is of middle and late Ordovician age. In the literature the group is most frequently spoken of as Chickamauga "limestone," even though shales, siltstones, and chert beds comprise a prominent but minor portion of the group. At the X-10 site of the Oak Ridge National Laboratory, the group is surprisingly thick, namely 1735 feet. The entire section of the Chickamauga is not to be seen at any continuous exposure; instead it must be gleaned from the composite of several sections. At the time of the writer's first field studies, outcrops were much more plentiful than today. Subsequent grading, seeding, and landscaping have covered many of the former outcrops so that today some of the sections which contributed toward knowledge of the stratigraphy are concealed. The core-drilling phase of the study revealed helpful details in part of the rock column.

Stratigraphic Subdivisions. -- In the Oak Ridge area, and particularly in Bethel Valley at the X-10 site of the Oak Ridge National Laboratory, variations in types of rock in the Chickamauga group permit separation into eight distinguishable and mappable subdivisions. (See Plate 11.) For practical purposes in this study these are referred to as "members" or units and are designated by letters "A" to "H" in ascending order in the column. A summary outline of the composite section of the Chickamauga group, in descending order of units, follows:

Unit	Description of Rock	Thickness (in feet)
H	Siltstone, calcareous, gray, olive, maroon; with shaly partings and thin limestone lenses	85
	Limestone of varied types, gray, olive-gray buff, drab; mostly thin-bedded; with argillaceous partings; weathers to shaly appearance; with fossiliferous zones	180
	Limestone, argillaceous (calcareous siltstone), gray, olive-gray, "pinkish" maroon; even-bedded, with shale partings	35
		300
G	Limestone of varied types, dark gray to brownish gray; mostly nodular with abundant black irregular clay partings; dense to medium-grained; mostly thin-bedded, partly massive; with shale partings; weathers to a lighter colored shaly or "nodular" appearance; with some fossiliferous horizons; mostly covered in lowlands	300
F	Siltstone, calcareous, alternating with shale; olive-gray to maroon; even-bedded; laminated; weathers to a red shaly appearânce; produces a slight rise in topography; a very distinctive unit	25
E	Limestone, mostly gray to drab, partly pinkish maroon, mottled; brittle, thin-bedded to massive; with shaly partings	60
	Limestone, similar to "G" above, mostly covered in lowlands	220
	Calcareous shale and argillaceous limestone, gray to buff; in alternating thin even beds; yielding small roundish slabs upon weathering, with yellow-buff color	45

Unit	Description of Rock	Thickness (in feet)
	Limestone of varied types, gray; mostly argillaceous and nodular; in thin irregular beds with shale partings; abundant fossils	55
		380
D	Limestone and chert; limestone is gray to olive-gray, in part nodular, shaly, and thin-bedded; in part massive; with abundant chert in thin, even, bands, breaking into angular fragments upon weathering; produces a chain of low hills .	160
C	Shale, calcareous, olive-gray to light-maroon; fissile; evenly-laminated	10
	Limestone of varied types, gray; fine to coarse-grained, partly crystalline, partly nodular; mostly massive; with occasional patches of chert; partly fossiliferous; "quarry beds" . . .	105
B	Siltstone, in even beds up to 2 feet thick, laminated, alternating with calcareous shale; olive-gray, buff, maroon; some limestone, non-resistant; more shale at base	215
A	Limestone of varied types, dark gray to buff; with shale partings; with gray to black chert in nodules and lenses	80
	Chert, thin-bedded, with shaly partings	15
	Siltstone, calcareous, olive-gray to maroon; weathers to shaly appearance	30
	Siltstone and chert, in alternating beds; siltstone is calcareous, gray, olive, maroon; weathers to shaly appearance; with abundant granular chert in even beds up to 6 inches thick, breaking into angular blocks upon weathering. . .	90
	Limestone; mostly covered	25
		240
	Total Thickness	1735

Special Features. — Although several still-smaller subdivisions can be recognized and traced across the area, the eight units as outlined above suggest sharpest contrasts and greatest practical worth in this study. Treatment of many academic aspects and problems associated with the stratigraphic details, especially as regards relationships with the Chickamauga rocks in other localities, is here omitted. Because the basal unit "A" is characterized by superabundance of chert it has been confused with the Knox dolomite which lies directly beneath, and was so mapped by Keith in the Loudon folio. The next higher unit "B" carries the most prominent calcareous siltstone beds, maroon to olive-gray, with alternating shale and with occasional pure limestone layers. It lacks the bedded chert which prevails in the unit beneath. Unit "C" carries the purest and most massive limestone of the group. It is, therefore, the most valuable quarry stone, and is utilized as such in the Oak Ridge area. This unit contains some crystalline layers which resemble the Holston "marble" found in belts farther east. Next above is another cherty unit, "D." It differs mainly from the basal chert unit by the lack of the prominent maroon color, and by having "slabby" limestone, instead of siltstone, alternating with the chert. Although most of the chert occurs in thin, even bands, it constitutes such a high proportion of the rock as to cause a chain of low hills as a topographic expression along the northwest side of Bethel Valley. The southeast dip-slopes of these hills are strewn with a heavy cover of angular chert blocks which came from the weathering of this unit. In unit "E" there are lumped together non-descript, gray limestones of varied types, with thin shaly partings. The most highly fossiliferous beds of the Chickamauga group occur at the base of this unit. Most of the limestone of the unit is characterized by numerous, closely spaced, irregular, black clay-partings which give the rock a "nodular" appearance where weathered. Although the fresh layers appear to be massive, they readily separate into thin, "slabby," brittle layers upon weathering. For stratigraphic discrimination as well as for mapping purposes, unit "F" is the most important of the group. This maroon siltstone and shale separates the rock of unit "E" below from the similar non-descript limestone, unit "F," above. Although it is partly calcareous, its argillaceous and silty predominence serves quite likely as a stratigraphic trap to avert free flow and interchange of ground waters between the thick adjoining limestone units. Its greater resistance to decomposition is expressed by a slight rise in topography with but a thin cover of soil. The prevailing lithology of unit "G" is much like that of "E" described above. This is the unit that lies beneath both the settling pond and the Bethel Valley burial grounds at the Oak Ridge National Laboratory. The next unit, "H," contains a wide variety of lithologic types that are not differentiated in this study. The occurrence of pinkish-maroon, calcareous siltstone beds at the base marks the line of separation from the underlying unit. Higher up is a mixture of limestones which are partly similar to those of unit "G". Still higher there occur somewhat variegated, laminated siltstones, limestones, and shale, of prevailingly dull-maroon color. This laminated zone weathers to considerable depth leaving a reddish shale-like appearance. It is conceivable that this zone may belong to the Rockwood (Sequatchie) formation instead of the Chickamauga. Its uppermost limit is cut out in the Laboratory area by the thrust fault along Haw Ridge.

Higher Units

Within the Oak Ridge area there are isolated occurrences of the Rockwood, Chattanooga, and Ft. Payne formations. However, discussion of them is omitted in this report inasmuch as they do not occur in the X-10 area of the Oak Ridge National Laboratory and have no bearing, therefore, upon this study.

GEOLOGIC STRUCTURE

The direction of dip of all of the rock formations in the Oak Ridge National Laboratory (X-10) area is southeast, consistent with the prevalent situation thruout the Valley and Ridge Province of eastern Tennessee. With the exception of a few outcrops, the angle of dip is within the range of 30-40 degrees, the average being 36 degrees. The average direction of strike within the laboratory area is north 58° east. This is a slight departure from the average of north 56° east for Bethel Valley as a whole. Minor flexures in the rock are unusual in contrast with the monotonous regularity of most of the strata. Most striking of such secondary folds is a small anticline in unit "A" of the Chickamauga formations, exposed in a cut along the White Wing road across Chestnut Ridge, west of the Laboratory. On the whole, however, the attitude of the formations is remarkably uniform within the immediate site of the Laboratory. (See Plates 2 and 12.)

A significent thrust fault occurs along Haw Ridge at the southeast side of Bethel Valley where the resistant siltstone (quartzitic) strata of the Rome formation have been thrust over the upper units of the much younger Chickamauga group. The trace of the fault follows along the northwest-facing slope of the ridge, at various elevations below the crest which is on the upthrow side. The average strike of the fault-surface is north 56° east; the dip is to the southeast at an undetermined angle. Field observations and calculations suggest a fairly high angle of dip probably as great as 45°, thus slightly in excess to that of the bed-rock layers. The stratigraphic throw of the fault is more than 5500 feet. Whiteoak Creek crosses the fault where it enters the gap through Haw Ridge just south of the laboratory. The fault was pierced by the core drill in two places in this vicinity, namely in holes Nos. 29 and 50. (See Plates 2 and 12.)

GEOLOGIC MAP AND STRUCTURE SECTION

The geologic maps and accompanying structure section of the X-10 area of the Oak Ridge National Laboratory, Plates 2, 3-10, 12, were prepared by Harry J. Klepser. The detailed mapping project on the scale of 1 inch to 100 feet was considered requisite to this study. (See Plates 3-10.) From them can be seen the accurate positions of the various types of rock strata in relation to potential sources of contamination, and, in turn, to factors involved in movements of ground waters. Greatest field attention was given the eight units of the Chickamauga group which have been carefully traced and mapped individually. The numerous dip-strike symbols readily reveal the structural conditions. The various formations and sub-units come to the surface along northeast-southwest trending, parallel belts. Since the direction of dip is southeast, the strata are oldest at the northwest side of the area and are progressively younger southeastward as far as the fault where the much older Rome formation occurs. Hence from there, southeastward, the strata are likewise progressively younger across Melton Valley to Copper Ridge. The maps show some, but not all, of the buildings and plant structures of the Laboratory, as well as contour lines and drainage pattern. Since the maps were made there have been many changes in roads, buildings, and other structures at the X-10 site.

GEOLOGIC FORMATIONS AT POTENTIAL SOURCES OF CONTAMINATION

At the X-10 unit of the Oak Ridge National Laboratory the tank farms into which fluid wastes from various sources are piped lie upon unit "E" of the Chickamauga group. The earthen-diked settling ponds which receive the fluid discharges from the tanks rest upon unit "G" of the group, and the small retention pond nearby upon the same unit. Whiteoak Creek, which receives the overflow from these ponds, runs first along unit "G" for a short distance, then across unit "H" to Haw Ridge gap where the fault is crossed. The creek thence flows across the Rome formation and finally onto the Conasauga shale which holds Whiteoak Lake. A small old burial ground, some 300 feet south of the main settling pond, where canned solid waste has been buried, rests upon limestones of unit "H." The main burial ground in current use, where solid wastes and contaminated materials and discarded equipment are buried, lies upon unit "G," the same unit which holds the settling ponds. Unless there should be breaks and leaks in the tanks, drainage lines, etc., of the liquid disposal system, the potential sources of underground contamination are the retention and settling ponds, Whiteoak Creek, and the burial grounds. Greatest of all is the main settling pond with a capacity of 1,600,000 gallons and an area of about 62,000 square feet. (See Plate 2.)

Unfortunately, the settling ponds and the course of Whiteoak Creek to where it crosses the fault in the gap, rest upon limestones, units "G" and "H," which are susceptible to underground solution and to the development of open voids with consequent increase in permeability. The prevalent type of limestone in these units is compact, dense or fine-grained in texture, occurring in thin beds with innumerable argillaceous partings interwoven throughout the rock. In addition there are calcareous, shaly layers separating the thin limestone beds. All of this rock, therefore, is devoid of any significant primary porosity. However, small secondary openings in the rock brought about thru solution by ground waters exist in minor amounts as revealed by the core drilling. This particular type of limestone does not favor development of large caverns which may characterize purer and more massive types. The large burial ground rests upon the same type of rock as the settling pond.

Drill cores reveal the rock at the fault zone to be quite dense. Original porosity has been sealed by mineralization. It is, therefore, highly improbable that any contaminated waters from Whiteoak Creek percolate thru this zone. The Rome formation which underlies Whiteoak Creek immediately downstream from the fault is composed of siltstone and silty shale which is also compact and comparatively impervious. The siltstone (or fine-grained sandstone) is dense and quartzitic. The most impervious of all geologic formations which underlie potential sources of contamination is the Conasauga shale, especially the Pumpkin Valley member at the base. Whiteoak Lake and its inflowing stream lie upon this formation. The shale is argillaceous, compact, and non-porous.

Interbedded with it are thin "sheets" of dense siltstone, generally less than one inch thick, and occasional limestone lenses. An air-pressure test of a drill hole in this shale suggested a lack of obvious permeability. The southeastern side of Whiteoak Lake encroaches upon interbedded limestone amidst the shale in the upper part of the Conasauga unit.

CHAPTER IV. SUB-SURFACE GEOLOGY AS REVEALED THRU CORE DRILLING

MULTIPLE PURPOSE OF THE DRILLING PROGRAM

Core drilling in connection with the study of geologic conditions at the X-10 site of the Oak Ridge National Laboratory was undertaken for several purposes, namely: (a) to supplement the knowledge of stratigraphy and structure obtained from surface, areal studies; (b) to reveal, through rock cores, details in lithology, especially as bearing upon texture and porosity; (c) to determine the existence and magnitude of solution channels (if any) in the rock; (d) to provide rock cores to be analyzed for radioactive contamination; (e) to provide wells for collecting water samples for analysis; (f) to provide exploratory wells for radiation detection by means of radiologging; and (g) to provide pertinent data on the hydrology of the area, especially as regard water-table levels and migration of ground waters.

SCOPE OF THE DRILLING PROGRAM

The program called for a total of 4500 feet of NX core drilling distributed among 51 holes, ranging in length from 50 to 300 feet. All holes except one were drilled vertically. Three drilling rigs were operated simultaneously. Drilling started on December 16, 1949, and ended on March 22, 1950. Hole No. 1, underneath the main settling pond, was drilled for 300 feet at an angle of 55 degrees from the horizonal so as to cut the bedding planes of the strata at approximately right angle. Forty eight drill holes are located in Bethel Valley; two on the flank of Haw Ridge at the margin of Bethel Valley; and one near the northwest margin of Whiteoak Lake in Melton Valley. The holes were numbered approximately in the chronological order of the drilling. (For locations, see Plates 2 and 13.) The spacing of the holes was determined from prior study and knowledge of the areal geology in relation to potential sources of contamination, and from the contemplated needs for hydrologic data. Twelve holes, spaced from approximately 75 to 100 feet apart, encircle the settling pond; 10 holes encircle the main burial grounds; two holes are located so as to pierce the fault at Haw Ridge; one hole is in the Conasauga shale near Whiteoak Lake; and the remaining holes are situated along Bethel Valley bottom between the settling pond and the main burial grounds and in otherwise appropriate positions for purposes of hydrologic information. Depth of mantle rock, at the time of drilling, ranged from three to 25 feet. At all holes NX casing was set thru the overburden and was left protruding well above the surface of the ground. Thirty of the holes start in unit "G" of the Chickamauga rock group; nine in unit "H"; seven in unit "E"; two in unit "F"; two in the Rome formation at the fault; and one in the Conasauga shale at Whiteoak Lake. These relationships can be gleaned best from Plate 2 and from Table 1.

RECORD OF EXPLORATORY DRILLING

Table 1, which follows, gives specific data on the 51 exploratory wells which were drilled. The X-10 plant coordinates of all well-locations have been accurately determined by a precise horizontal survey. The cores of all wells have been logged and the records placed on file. The boxes of rock core have been stored and are available for any future reference.

TABLE 1. COMPARATIVE DATA ON EXPLORATORY WELLS

No.	When drilled, 1949-1950	Angle Degrees	Depth of Drilling (feet) 1/	Thickness (feet) of overburden above bedrock	Elevation of top of casting 2/	Elevation of water level, June 20, 1950 3/	Geologic Units encountered
1	Dec. 19 - Jan. 10	55	300.0	13.0	784.46	776.48	G, F
2	Dec. 16 - Dec. 22	90	100.0	9.2	779.52	772.12	G
3	Dec. 21 - Jan. 6	90	250.7	12.0	838.58	825.38	G, F
4	Dec. 27 - Jan. 5	90	100.2	7.7	787.98	777.24	G
5	Jan. 9 - Jan. 11	90	100.0	10.5	842.77	825.75	G
6	Jan. 4 - Jan. 9	90	100.0	11.3	790.62	778.72	G
7	Jan. 10 - Jan. 15	90	100.0	9.0	780.20	777.31	G
8	Jan. 11 - Jan. 13	90	100.0	8.0	778.52	776.49	G
9	Jan. 12 - Jan. 16	90	100.0	22.0	848.28	825.69	G
0	Jan. 16 - Jan. 20	90	100.0	10.0	780.05	776.45	G
1	Jan. 16 - Jan. 18	90	100.0	9.0	778.59	775.66	G
2	Jan. 19 - Jan. 25	90	100.0	9.0	778.53	772.15	H, G
3	Jan. 20 - Jan. 26	90	100.0	10.0	787.87	774.93	H, G
4	Jan. 26 - Jan. 31	90	100.0	10.2	788.83	775.73	H, G
5	Jan. 17 - Jan. 20	90	100.0	25.0	848.89	814.94	G
6	Jan. 23 - Jan. 26	90	100.0	12.0	840.28	810.52	G, F
7	Jan. 26 - Jan. 30	90	100.0	9.0	782.16	779.97	G
8	Jan. 31 - Feb. 2	90	100.0	13.0	778.36	776.27	G
9	Feb. 2 - Feb. 7	90	100.3	13.5	783.35	771.63	H
0	Jan. 27 - Feb. 3	90	100.0	12.5	836.22	819.20	F, E

TABLE 1. COMPARATIVE DATA ON EXPLORATORY WELLS

No.	When drilled, 1949 - 1950	Angle Degrees	Depth of Drilling (feet) 1/	Thickness (feet) of overburden above bed-rock	Elevation of top of casting 2/	Elevation of water level, June 20, 1950 3/	Geologic Units encountered
21	Feb. 7 - Feb. 10	90	100.0	12.0	834.30	807.75	G, F
22	Feb. 13 - Feb. 18	90	100.0	10.5	825.69	810.60	G, F
23	Feb. 17 - Feb. 21	90	100.0	10.0	827.50	818.57	G
24	Feb. 4 - Feb. 8	90	100.0	5.0	779.26	777.84	G
25	Feb. 8 - Feb. 10	90	50.0	6.0	790.12	784.73	G
26	Feb. 10 - Feb. 14	90	50.0	20.0	779.62	770.76	H
27	Feb. 9 - Feb. 10	90	50.0	8.5	778.88	771.68	H
28	Feb. 13 - Feb. 15	90	100.0	23.0	790.47	776.14	H
29	Feb. 17 - Feb. 29	90	198.0	8.0	797.06	769.48	Rome, H
30	Feb. 15 - Feb. 16	90	50.0	6.7	782.78	777.01	G
31	Feb. 16 - Feb. 17	90	50.0	3.0	786.82	781.96	G
32	Feb. 22 - Feb. 24	90	100.0	8.7	839.59	824.78	G
33	Feb. 20 - Feb. 21	90	50.0	4.0	799.40	796.53	E
34	Feb. 22 - Feb. 23	90	50.0	5.8	794.30	788.04	E
35	Feb. 23 - Feb. 26	90	50.0	15.0	801.90	786.48	E
36	Feb. 28 - Mar. 1	90	50.0	7.0	818.47	802.14	E
37	Mar. 1 - Mar. 2	90	50.0	6.2	800.63	781.04	E
38	Mar. 2 - Mar. 3	90	50.0	20.6	831.38	803.28	E
39	Mar. 7 - Mar. 8	90	50.0	6.5	820.62	dry	E
40	Mar. 9 - Mar. 10	90	50.0	4.0	808.07	781.90	F, E

TABLE 1. COMPARATIVE DATA ON EXPLORATORY WELLS

No.	When drilled, 1949 - 1950	Angle Degrees	Depth of Drilling (feet) 1/	Thickness (feet) of overburden above bed-rock	Elevation of top of casting 2/	Elevation of water level, June 20, 1950 3/	Geologic Units encountered
41	Feb. 24 - Feb. 27	90	50.0	10.0	831.88	799.42	G, F
42	Feb. 28 - Mar. 2	90	50.0	1.0	833.26	811.79	G
43	Mar. 2 - Mar. 3	90	50.0	9.5	798.80	792.66	G
44	Mar. 7 - Mar. 8	90	50.0	9.0	813.10	788.82	G
45	Mar. 3 - Mar. 8	90	50.0	6.5	791.48	788.57	G
46	Mar. 9 - Mar. 10	90	50.0	3.0	787.62	783.87	G
47	Mar. 11 - Mar. 13	90	50.0	9.0	796.45	786.45	G
48	Mar. 9 - Mar. 10	90	50.0	11.0	784.90	778.51	H
49	Mar. 7 - Mar. 8	90	50.0	8.0	778.94	774.90	H
50	Mar. 1 - Mar. 6	90	90.0	6.0	829.11	813.28	Rome, H
51	Mar. 16 - Mar. 22	90	161.0	3.0			Conasauga

1/ Hole No. 1 is inclined, 55° from horizontal; 300 feet is length, not depth.

2/ 3/ Measurements by G. D. DeBuchananne

For the purpose of this report it is regarded unessential to publish the logs of all the 51 wells. Logs of but two wells are submitted below. They illustrate the kind of detail revealed in the core drilling. The first is that of the oblique hole which runs beneath the settling pond; the second, of hole number 29 which cuts the fault at the gap of Whiteoak Creek across Haw Ridge. The first hole is mainly within the "G" unit of the Chickamauga rock group, piercing the "F" unit near the base. The second starts in the Rome formation and then, after penetrating the fault, pierces the "H" unit of the Chickamauga.

Log of drill hole No. 1, angle 55°

Location, on dike at southeast side of settling pond, running obliquely northwestward beneath the pond. Length of hole, 300 feet; altitude top of casing, 784.46 feet; altitude bottom of hole, 538.7 feet

Core pulls, in feet	Kind of rock	Length of core, in feet
0.0-13.0	Recent mantle rock	
13.0-22.3	Chickamauga group, unit "G": Limestone, gray, mostly dense to fine grained; occasional coarser patches with shell fragments; with abundant irregular, thin, dark-gray to black argillaceous partings, closely spaced, branching and interconnecting, producing a brecciated or "nodular" appearance; occasional slickensided surfaces along the dark partings; miniature stylolite-seams in various directions	7.0
22.3-32.3	Same as above	10.0
32.3-43.0	Same as above	10.0
43.0-53.0	Similar to above; clay partings more abundant; with numerous, prominent bryozoans	10.0

Log of drill hole No. 1 (continued)

Core pulls, in feet	Kind of rock	Length of core, in feet
53.0-55.0	Same as above	2.0
55.0-66.0	Same as above	10.0
66.0-75.0	"Nodular" limestone, similar to above but coarser in appearance due to abundant shell fragments; with finely-disseminated pyrite in scattered patches	8.5
75.0-83.0	Same as above	7.6
83.0-93.0	Limestone, dark gray; with abundant thin, closely-spaced, grayish-black, argillaceous laminae, slightly calcareous; with elongated, finger-like white crystalline masses, transverse to bedding, resembling bryozoans. This limestone is not as "nodular" in appearance as that above	
93.0-103.0	Similar to above	10.0
103.0-106.5	Same as above	3.5
106.5-115.0	Similar to above; clay laminae become more irregular and less abundant downward	7.5
115.0-125.0	Limestone, gray, dense to fine grained; occasional coarser patches with shell fragments; with abundant irregular, thin, dark-gray to black argillaceous partings, closely spaced, branching and interconnecting, producing a brecciated or "nodular" appearance; with miniature fractures, transverse to bedding	9.9
125.0-135.0	Similar to above; argillaceous partings becoming less abundant downward; limestone has uniform, fine-grained texture	10.0
135.0-145.0	Same as above	10.0
145.0-155.0	Similar to above	10.0

Log of drill hole No. 1 (continued)

Core pulls, in feet	Kind of rock	Length of core, in feet
155.0-165.0	Limestone, gray, mostly dense to fine-grained with few coarse-grained patches; with abundant irregular, thin, dark-gray to black argillaceous partings, closely spaced, branching and interconnecting, producing a "nodular" appearance	
165.0-174.0	Same as above	9.0
174.0-184.0	Same as above	10.0
184.0-188.0	Same as above	4.0
188.0-196.0	Same as above	7.8
196.0-202.0	Same as above	6.0
202.0-212.0	Same as above	9.6
212.0-216.6	Rock, same as above; with two, small solution cavities (channels), about one-half inch wide, at 214.6 and 215.6 feet	4.5
216.6-218.6	"Nodular" limestone, similar to above	2.0
218.6-225.0	Same as above	5.5
225.0-235.0	Same as above	10.0
235.0-245.0	Same as above	10.0
245.0-255.5	Similar to above; with numerous, thin calcite veins	10.0
255.5-265.5	Similar to above; fewer calcite veins	10.0
265.5-275.5	Same as above	10.0
275.5-285.5	Similar to above; argillaceous laminae becoming more regular and thinner downward; becoming more shaly in appearance	10.0
285.5-295.5	Laminated limestone, similar to above, grading into siltstone beneath	2.7

Log of drill hole No. 1 (continued)

Core pulls, in feet	Kind of rock	Length of core, in feet
	Chickamauga group, unit "F":	
	Siltstone, calcareous, mostly purple-maroon; with bands of gray limestone, containing thin, maroon, silty laminae	7.3
295.5-300.0	Limestone, silty, olive-gray; with thin, maroon, silty laminae	4.4
	Total amount of core	278.8
	Total length of hole	300.0

Log of drill hole No. 29, angle 90°

Location at gap of Whiteoak Creek thru Haw Ridge. Depth of hole, 198 feet: altitude top of casing, 797.06 feet; altitude bottom of hole, 599.06 feet

Core pulls, in feet	Kind of rock	Length of core, in feet
0.0-8.0	Recent mantle rock	
	Rome formation:	
8.0-21.6 (two pulls)	Sandstone, broken pieces	1.6
21.6-31.0	Sandstone, gray, brown, maroon; fine grained, quartzitic; with scattered clay partings; with calcite veins; badly broken; poor recovery; missing rock probably shale	1.5
31.0-37.0	Same as above	2.5
37.0-47.0	Same as above	2.7
47.0-56.6	Same as above	4.7
56.6-63.0	Dolomite, siliceous, dark gray; saccaroidal texture; abundant calcite veins; poor recovery, with shaly rock missing	2.8
63.0-67.6	Same as above	1.8
67.6-73.0	Same as above	1.8

Log of drill hole No. 29 (continued)

Core pulls, in feet	Kind of rock	Length of core, in feet
73.0-77.0	Same as above; more massive; better recovery	2.9
77.0-81.0	Same as above	2.7
81.0-86.6	Same as above; massive	5.3
86.6-96.6	Same as above	9.5
96.6-101.6	Same as above	4.0
101.6-103.6	Sandstone, gray to pinkish-maroon; fine grained, quartzitic, with clay partings; with calcite veins; brecciated in places	1.4
103.0-107.0	Same as above	3.5
107.0-109.0	Same as above	1.9
109.0-112.6	Same as above	3.6
112.6-115.6	Same as above; dolomite at base	3.0
115.6-186.0 (15 pulls)	Fault zone, with confused broken mixture of brecciated dolomite, quartzitic sandstone, and shale; gray, olive, buff, pink, maroon; with slickensided black partings. Thin zones of dark-gray gouge at 112 feet, 127 feet, and 186 feet	
	Chickamauga group, unit "H":	
186.0-187.0	Limestone, gray, dense to fine grained; with grayish-black, irregular, wavy, argillaceous partings; "nodular" appearance	1.0
187.0-190.0	Same as above	2.5
190.0-194.0	Same as above	3.0
194.0-198.0	Same as above	2.5
	Total amount of core	106.0
	Total length of hole	198.0

SUMMARY OF GEOLOGIC FINDINGS FROM CORE DRILLING

A study of the cores substantiated the general stratigraphic and structural relationships which had been determined from surface explorations and revealed many additional details brought out in the preceeding chapter. As previously stated, the non-descript limestones of zone "G" of the Chickamauga group, which underlie the settling pond and the burial ground, are quite compact and non-porous except where secondary voids have been developed. The drilling revealed several, though not numerous, solution channels of small size in these limestones. Most are but an inch or so in diameter; the largest to be pierced, about one foot. Drilling waters were lost through underground channels in holes Nos. 13, 16, 21, 38, 39, and 44. Holes Nos. 29 and 50 pierced the thrust fault at Haw Ridge. These holes started in the Rome formation and finished in unit "H" of the Chickamauga rocks beneath the fault surface. The cores reveal that the fault breccia and gouge are tightly cemented and therefore are quite impermeable. Quite likely, therefore, the fault would block any horizontal migration of ground waters that might come from the Chickamauga rock belt which lies on the northwest. Furthermore, the unbroken rock of the Rome formation adjoining the fault is also non-porous, consisting of shale, quartzitic siltstone, and siliceous dolomite.

Hydrologic conditions as revealed from the drill holes are discussed in Chapter V. Findings as regards underground radioactive contamination are given in Chapter VI.

CHAPTER V. HYDROLOGIC FEATURES
(By George D. De Buchananne)

CLIMATE IN GENERAL

Characteristics of the climate bear directly upon the hydrologic features of any area. Temperature range, duration of growing season, and the precipitation intensity and distribution as to time, influence the recharge to and discharge from ground-water bodies. The climate of the Oak Ridge area falls within the humid subtropical classification. Table 2, following, gives rainfall and temperature data for the Oak Ridge area as supplied by the United States Weather Bureau:

Table 2

Monthly Precipitation and Temperature, Oak Ridge, Tennessee

	Normal Rainfall	Maximum Rainfall 1944-50	Minimum Rainfall 1944-50	Normal Temperature
Jan.	4.9	11.22	2.40	36.4
Feb.	5.0	8.52	1.89	38.8
March	5.1	5.75	3.18	45.9
April	5.5	6.11	1.40	56.9
May	4.0	7.01	1.85	65.2
June	4.2	5.87	1.70	72.8
July	4.8	6.05	2.47	76.2
Aug.	4.8	4.90	1.80	73.8
Sept.	3.6	12.84	1.07	68.7
Oct.	2.6	6.43	1.20	57.4
Nov.	3.8	12.00	1.01	47.1.
Dec.	4.1	5.55	2.74	40.4
Annual	52.4			

Table 2 indicates that the normal temperature ranges from 76.2 degrees Fahrenheit in July to 36.4 degrees in January. The average frost-free period of about 196 days extends from April 11 to October 24, thus providing ample time for all crops normally grown in this area. Frost has been recorded as late as May 10 and as early as September 26. Transpiration and evaporation, of course, would utilize a substantial part, or perhaps most of the precipitation during the frost-free period. Thus, recharge to the ground water would be at a minimum during the growing season.

Table 2 also shows that the average annual precipitation is 52.4 inches and that the high and low precipitation months are April and October respectively. The normal range of only 2.9 inches between the two monthly extremes, indicates that rainfall distribution is fairly uniform through the year. Normally some of the annual precipitation falls as snow during the winter, but it generally melts within a day or two.

SURFACE WATER

In Chapter II, "Location and Physiography," the surface drainage in relation to topography at the X-10 site of the Oak Ridge National Laboratory is discussed. The immediate site of the Laboratory lies in Bethel Valley and is drained by a small stream, Whiteoak Creek, and its tributaries. Low divides in the trough of Bethel Valley separate the Whiteoak drainage from that of Raccoon Creek to the southwest and Bearden Creek to the northeast. (See Plate 1.) Just south of the Laboratory, Whiteoak Creek flows out of Bethel Valley through a narrow water gap across Haw Ridge, to where it is joined by Melton Branch and then flows south-southwest along another trough into the Clinch River some two miles away. Between the junction with Melton Branch and the Clinch River, however, the Whiteoak Creek is ponded in Whiteoak Lake reservoir, as discussed in Chapter II. The elevation of the junction of Whiteoak Creek and the Clinch River is that of Watts Bar Reservoir, 741 feet; of the top of the spillway at Whiteoak Lake, 750 feet; of Whiteoak Creek at Haw Ridge gap, 770 feet; of the drainage divide in Bethel Valley northeast of the Laboratory, approximately 860 feet; and of the divide southwest of the Laboratory, approximately 835 feet. The surface drainage of the Laboratory area, therefore, is to the Clinch River, by way of Whiteoak Creek.

Discharge figures on Whiteoak Creek are not available as gaging stations were only recently installed. It is possible, however, to draw some tentative conclusions by analyzing the two years of record from the Buffalo Creek drainage basin (located some 24 miles northeast of this area) which is similar topographically and geologically to the Whiteoak Creek drainage basin above Haw Ridge. The drainage basin of Whiteoak Creek above a point opposite test well No. 30 is about two sq. miles. The drainage basin above the gaging station on Buffalo Creek is 9.45 sq. miles.

Discharge figures from the Buffalo Creek gaging station[1/] for

[1/] Unpublished records supplied by the U. S. Geological Survey, Surface Water Branch.

the period of September 1947 to September 1949 indicate that peak discharges generally occur during December, January, February, and March, and minimum flows occur during September and October. The mean annual discharge, for the brief period of record, is 13.7 sec.-ft. which represents a runoff of about 1.45 sec.-ft. per sq. mile. A peak discharge of 757 sec.-ft. occurred on February 13, 1948, and a minimum discharge of .3 sec.-ft. on September 17, 1948. The peak discharge occurred after a period during which the total rainfall had been 4.45 inches during a 48-hour period. The minimum discharge occurred after a period during which no rain had fallen for seven days and only 0.68 of an inch of rainfall had fallen during the preceding 31 days.

If the minimum discharge of Buffalo Creek is assumed to represent only ground-water discharge, then a base runoff of about .03 sec.-ft. per sq. mile is indicated. This, however, would not be the total ground-water discharge, for it does not take into account evapotranspiration losses and losses via subsurface drainage through caverns which are presumed to exist in the area, based on knowledge of caverns occurring downstream from the gaging station. Considering the types of vegetation and amount of agriculture in the respective areas, and noting the lack of known large solution cavities in the Whiteoak Creek watershed it is assumed that the minimum runoff per square mile would be higher for Whiteoak Creek than for Buffalo Creek. It is estimated that the minimum runoff would be approximately .15 sec.-ft. per sq. mile for the two-square-mile portion of the Whiteoak Creek watershed that lies upstream from the point where discharge from the Oak Ridge Laboratory settling basins enters the stream.

GROUND WATER

Water that falls on the earth's surface is disposed of by evaporation, by infiltration into the ground, or by overland runoff. That which runs off overland is called surface water and that which infiltrates into the ground is called subsurface water.

Subsurface water in turn has been subdivided into two general classifications.[2] That part of subsurface water which is in the zone

[2] Meinzer, O. E., The Occurrence of Ground Water in the United States: U. S. Geol. Survey Water-Supply Paper 489, 1923.

of saturation is called "ground water" or "phreatic water," and that part of subsurface water above the zone of saturation -- called the zone of aeration -- is termed "suspended subsurface water" or "vadose water." In the zone of saturation all interstices of permeable rocks are saturated with water under hydrostatic pressure, whereas in the zone of aeration the interstices are not filled with water or are only temporarily filled with water in transit from the land surface to the zone of saturation. The zone of saturation is the zone which yields water to wells while the zone of aeration supplies moisture to the roots of plants.

The occurrence of water in the rocks of the earth's crust is influenced largely by the character, distribution, and structure of the rocks, and by the size, shape and continuity of the interstices in the rocks. Many rocks have numerous interstices of very small size whereas others are characterized by a few large openings, such as joints or caverns. In many rocks the interstices are connected, permitting water to percolate through; in some rocks, however, the interstices are largely isolated with little or no opportunity for movement of water. The property of a rock containing interstices is called its porosity. Porosity is expressed as the percentage of the total volume of rock that is not occupied by solid material. The porosity of a rock depends chiefly on the shape and arrangement of its particles and their degree of assortment, the amount of cementation and compaction, the amount of solution by circulating waters, and the amount of fracturing. The rate at which water can be transmitted through a unit cross section of rock under unit difference of pressure per unit distance is a measure of its permeability. Permeability and porosity are not synonymous. For example, clay is one of the most porous of earth materials, but the pores are so small that it is one of the least permeable. A rock that is devoid of interstices, or contains only isolated interstices, would be called impermeable.

The upper surface of the zone of saturation in ordinary permeable soil or rock is called the water table. If a well is drilled so as to penetrate the saturated zone, water will flow into the well and will stand in the well at the same elevation as the adjacent water table. The water table will be affected by climatic conditions, rising during wet periods and falling during dry periods. During periods of excessive precipitation the water table may rise to the land surface; ground water being discharged in seeps where the water table intersects the land surface. In some geologic settings one or more saturated zones may occur above the water table as a result of discontinuous impermeable zones which, by retarding downward movement of soil water, cause small perched water bodies to form. During dry weather these perched water bodies commonly lose their water by evapotranspiration processes, by seepage at the surface, or by slow drainage to the true water table below. A formation, group of formations, or part of a formation that is water-bearing is termed an aquifer.

Accretions of water to the ground water reservoirs are called recharge. The amount of recharge is equal to the amount of water available at the surface minus surface runoff, evaporation, and transpiration. The physical properties of the soil and of the underlying saturated zone, the amount and distribution of precipitation, the temperature, the kind of topography, and the types of vegetation on the land surface are all factors determining the amount of recharge.

The water in an aquifer is constantly moving from points of recharge to points of discharge. The rate of movement depends on the permeability of the aquifer and the steepness of the gradient from the point of recharge to the point of discharge; and the thicker the aquifer the larger will be the volume of water moved. This principal is expressed by an adaptation of Darcy's law of laminar flow which states that the quantity of water moved is the product of the permeability of the aquifer, the cross sectional area through which the movement occurs, and the hydraulic gradient.

Several different methods may be used to determine the rate and direction of movement of ground water. Tracers in the form of dyes or electrolytes may be added to ground water to determine the time required for movement from one point to another. The permeability of water-bearing materials may be determined in the laboratory either by mechanical analyses or by use of discharging or nondischarging apparatus; and in the field by conducting controlled pumping tests permitting computation of the hydrologic properties of the aquifer. Contour maps can be constructed showing the configuration of the water table and facilitating determination of hydraulic gradients and the direction of ground-water movement. All of these methods are in use, but each presents problems. In using tracers consideration has to be given to absorption, adsorption, and dilution as well as detection of the tracer at the observation point. Laboratory determinations of permeability utilize at best only a small portion of the water-bearing material which often has been disturbed in the collection process and thus is not truly representative of the aquifer. Pumping test techniques are based on the assumption that the aquifer is homogeneous, isotropic, and of indefinite extent, whereas in practice these conditions are rarely completely satisfied.

Ground-water recharge and movement away from areas of recharge necessitate some corresponding discharge of ground water at other locations. This discharge is by evaporation, transpiration, and by springs and seeps to surface streams. A moist zone, called the capillary fringe, in which water is drawn up by molecular attraction acting against gravity exists just above the water table. The thickness of this capillary fringe varies inversely with the size of the interstices. When the water table is so near the land surface that the capillary fringe intersects it, a considerable amount of ground-water evaporation takes place. Roots of plants which extend down into the capillary fringe and into the zone of saturation, conduct water up to the surface to be transpired through the leaves. In places where the water table intersects the surface, ground water is discharged as permanent springs, wet-weather springs, and seeps. These are the chief means by which ground water is discharged. Changes in amount of ground-water storage are determined by the summation of the measured discharge by each of these means.[3]

3/ Meinzer, O. E., Outline of Methods for Estimating Ground Water Supplies: U. S. Geol. Survey Water-Supply Paper 638-C, 1932.

The chemical quality of ground water is influenced by both the quality of the recharge water and the chemical character of the material through which the water moves. Under natural conditions the main source of recharge is precipitation, so that the chemical quality of the ground water is governed primarily by the character of the rock through which it moves. However, where the recharge water is contaminated (for example, surface streams which are contaminated by industrial waste), under certain ground-water conditions, contaminated water from the stream may percolate into the ground-water reservoir. Fortunately this situation is often alleviated because concentrations of certain types of contamination may be reduced by absorption, adsorption, chemical reaction or ion exchange processes occurring in the material through which the contaminated water percolates.

GROUND-WATER CONDITIONS AT THE OAK RIDGE NATIONAL LABORATORY

The water-table map (Plate 13) of the Oak Ridge National Laboratories area shows, by its close correlation with the topography and surface drainage, that ground water occurs under water-table rather than artesian conditions. Thus ground-water discharge contributes to the base flow of the surface streams in this area, and ultimately augments the flow of the Clinch River.

The water-table map was constructed by using depth-to-water-level observations on 50 tests wells dispersed throughout the area. The water-level observations were all made on the same day to give, as closely as was feasible, an instantaneous representation of the water-table configuration. Each measurement was converted to feet above mean sea level so that all would be related to a common datum plane. Contour lines at five-foot intervals were then constructed through points of equal elevations, incidentally reflecting the control of topography and surface drainage. The location of numerous wells around the settling basins made it possible to draw contour lines at one-foot intervals in this area with a fair degree of assurance. These one-foot contour lines show in detail the effect of water stored on the land surface in open basins above the water table. At present adequate control in the form of observation wells is not available to allow for the preparation of a map that presents an absolutely accurate picture of the water table; however, this map represents the most reasonable interpretation of the data now available, and doubtless is fairly reliable.

The depth to the water table varies with regard to the land surface. In general, the water table is a subdued replica of the land surface, rising slightly below the hills but occupying positions closer to the land surface in the valleys. The amount of soil overlying the bedrock seems to have little relation to the depth to water. This is as would be expected in limestone terranes where weathering and amount of residual soil cover varies with the solubility of the parent rock. Records of water levels in wells adjacent to permanent streams consistently indicate that ground water is being added to the streams; that is, the streams are effluent with respect to ground water.

The plant facilities constituting the X-10 unit of Oak Ridge National Laboratories may be divided arbitrarily into three broad groups, namely: (1) the laboratory building site and tank farms; (2) the main burial grounds; and (3) the liquid waste-disposal sites. The laboratory buildings and tank farms are located on the northwest slope of Bethel Valley where the depth to the water table is fairly great ranging from 5.6 to 25.1 feet. The main burial grounds are at a surface drainage divide where the depth to water ranges from 8.9 to 33.3 feet below the land surface. The liquid waste disposal sites, that is the settling basins, are located in the valley bottom near Whiteoak Creek where the depth to the water table ranges from one to 6.3 feet below the land surface.

Under water-table conditions, recharge of the aquifer can occur any place where water can infiltrate the soil. In the area covered by this study it would appear that recharge can and does take place throughout the area. The lithology of underlying geologic formations, the degree of fracturing of these rocks, and the amount and type of soil cover, all influence the rate of recharge. Detailed studies were not warrented over the entire area to determine the more permeable areas, but variation in fluctuations of the water table indicates that certain areas are more susceptible to recharge than others. This is believed to be due in part to the somewhat thinner cover and more permeable nature of the soil in the valley bottoms, versus the thicker more clayey cover and less permeable nature of the soil on the slopes.

The addition of liquids to the soil by operations in the X-10 area causes recharge of the ground-water reservoir. Similarly, any fluids which might be released, either through accident or structural failure of tanks or pipe lines, would pass downward through the zone of aeration into the zone of saturation where they would mingle with the natural ground water.

In the area covered by the X-10 plant site there are several places where natural recharge may be augmented by operations now practiced. These potential sites that should be considered are along the courses of pipe lines, buried tanks that retain or hold fluids, the open settling basins, and the streams into which waste fluids are discharged.

Pipe lines and storage tanks can be grouped together for consideration since both are presumed to be free of any leakage. However, should leakage result because of disturbance by man or nature, or through weakness caused by the fatigue of the materials used in the structures themselves, the released fluids would infiltrate downward through the zone of aeration to the saturated zone to recharge the aquifer. In most, if not all, cases the fluid-conveying or storage structures are buried in areas where the capillary fringe does not extend to or very near the land surface. Accordingly, if released, the fluids would be subjected primarily to gravity forces tending to move them downward to the saturated zone.

The open settling basins, which were constructed with no measures taken to prevent the downward percolation of fluids (construction discussed in Chapter I), should be recognized as a source of actual recharge. These basins were constructed in an area where the soil cover is presumed to be the most permeable and where the water table is close to the land surface. Water-level observations in this area show a quick response to precipitation and to the fluctuations of Whiteoak Creek indicating that the water has little difficulty moving through the soil.

Details are given in Chapter IVof this report concerning a drilling program which included the drilling of an oblique well beneath the largest settling basin. This well was later pressure-tested to determine whether interconnection existed between the well and the basin iteelf. The testing was accomplished in 50-foot cumulative increments working upward from the 250-foot level to the the 50-foot level. From the 50-foot level to the bottom of the casing the well was tested in separate 5-foot sections. Air pressures of about 90 lbs. per sq. inch were used to make these tests. Testing showed that from the surface to a depth of 50 feet in the inclined well there were four zones, each approximately five feet in length, where air could readily excape from the well through the openings in the rock formation to discharge, ultimately, at the basin surface. In testing the remainder of the well below the 50-foot depth several other zones of air leakage were noted, but sufficient control could not be maintained to determine their exact position. The testing did establish, however, that whenever the elevation of the water table underlying the basin and adjacent areas fell below the basin's surface elevation (about 788 feet) fluids from the basin could move downward into the aquifer.

Thus, these basins are potential sources of contamination of the water resources of the area. The volume and extent of the downward leakage from the basins is not known, nor the extent to which radiation products have accumulated in the material underlying the basins by processes of ion exchange and adsorption. It is not known whether these processes permanently fix the radiation products, or hold them until the level of radioactivity is below the limit considered safe; or whether these processes may be reversed by normal plant operation, or by accident. And it is not known whether the material so fixed to date represents a small fraction or a large fraction of the capacity of the soil and rock to fix such materials. Studies to determine these unknown factors should be undertaken at the earliest practicable time.

Whiteoak Creek receives discharge directly from the settling basins mentioned above and it is possible that in extended dry periods this discharge exceeds the natural flow of Whiteoak Creek at the site of the basins. As long as ground-water discharge accounts for the total flow of a stream there will be no recharge from the stream and if the stream should become completely dry then the water table could conceivably decline below the stream bed. Recharge to the aquifer would thus occur whereever water was added to the stream channel, as for example where the discharge from the settling basins is spilled into the channel of Whiteoak Creek. Contaminated water occasionally spreads over the flood plain of Whiteoak Creek, during flood periods, permitting ground-water recharge to occur.

Natural ground-water recharge would be augmented in the event of an accident which spilled contaminated fluids anywhere within the X-10 area. Although some of the fluids thus spilled would be lost by evaporation, some would be retained as soil moisture, and some would be held through absorption, adsorption, or base-exchange properties in the soil and rocks, but some would actually reach the water table and move down gradient in the aquifer. Even though the retentive processes mentioned above could conceivably account for all of the fluid, it should be remembered that the contaminating material itself would not be evaporated but would be left either on the land surface or just below the surface from where it might be carried downward during the next period of recharge; or perhaps it might be attached to the soil particles and later be scattered about as dust during dry periods.

As was pointed out before, it is believed that the aquifer can be recharged anywhere in the area. This means that any contamination that may be subjected to the downwind percolation of water may be added to the ground water. Particular sources of danger are the "burial grounds," and any other places where contamination may have fallen on the land surface.

The "burial grounds," which are described in detail in Chapter I, are used to bury materials which were contaminated through use or accident. The burial process consists of digging a trench through the soil mantle down to bedrock, placing contaminated material in the trench, and back-filling the trench with the original soil. The contaminated material in the "burial ground," being used at present, is located in the zone of aeration and probably above the capillary fringe of the water table. As recharge occurs from precipitation at the "burial ground," the contaminated material is subjected to leaching as the water moves through the zone of aeration. Possibly, however, owing to the nature of the contamination, its downward movement may be retarded by absorption of the soil so that it is merely transferred from the buried articles into the soil. Where this is the case consideration should be given to the possible future release of the contamination from the soil under some unforeseen conditions. If this should happen large concentrations might suddenly be added to the ground water rather than the gradual addition of small amounts over a long period of time.

Contamination which may be added to the atmosphere is called "air-borne contamination." This can originate from the normal operation practices or from burning of contaminated waste materials. Regardless of its origin, if the contamination falls to the ground it either will be carried off with the surface runoff or will be carried downward through the soil with the ground-water recharge. The possibility of the accumulation of this contamination through absorption by the soil and subsequent release requires the same consideration as the similar type of concentration and possible subsequent release of contamination from the "burial ground" areas.

MOVEMENT OF GROUND WATER IN THE X-10 AREA

From the water-table contour map (Plate 13) the general directions of movement of ground water and contamination can be inferred. The flow pattern of the ground water will be essentially a subdued replica of the topography. Thus watar flows from areas of high elevation to areas of low elevation and the principal movement is in directions normal to the contour lines. Displacement of the contour lines from the normal expected pattern shown that fluids from the settling basins are recharging the aquifer, forming a ridge-like structure on the water table. Note in particular the displacement of the 780-foot contour, to include the two smaller settling basins which have a surface elevation of about 782 feet, and the bending of the 778-foot contour to include the large settling basin, which has a surface elevation of about 778 feet.

The unusual pattern of water-table contours northwest of the settling basins is caused by recharge from the settling basins and the presence of a more permeable area created by a buried pipe line. This pipe line is in a ditch excavated in a clay soil and backfilled, which increased the soils permeability. This back-filled ditch acts as a drainage channel which allows a more rapid movement of ground water along its course. Water levels of the ditch are higher than those west of it due to recharge from the pond. This filled ditch has the same effect on the ground water as would an open ditch.

The water-table divide at the west end of the "burial ground" shows that ground water on the west side of the divide will flow toward the west into the Raccoon Creek drainage while water on the east side of the divide will flow east into Whiteoak Creek drainage. (See Plate 13.)

The rate of ground-water flow in this area is not known. Water level fluctuations indicate, however, that during rainy periods the water table is recharged rapidly through the permeable soil cover and following these periods the ground water is rapidly discharged. This is due in part to the topographic expression which provokes rapid drainage, and in part to the low porosity of the material which bears importantly upon the amount of water that can be stored. Examination of cores from the test wells shows that the porosity of these rocks is low and that the few existing openings are primarily small fractures and solution channels. The smallness of these openings and the slow recovery of water levels in test wells after pumping suggest that the movement of water in the bedrock is relatively slow.

AREAS OF DISCHARGE

It is known that ground-water discharge from the X-10 area occurs through springs, wet-weather seeps, the banks of Whiteoak Creek and its tributaries, and by evaporation, and transpiration. The springs in this drainage area are all small with individual discharge rates of less than 10 gallons a minute. Most of them are above the plant site and all are controlled by geologic factors. In wet weather small perched water bodies develop and discharge in numerous seeps along the slopes of the valley. Some of this seep water is evaporated, but some again filters into the soil and eventually reaches the water table.

The discharge of ground water into Whiteoak Creek and its tributary streams varies with climatic conditions, and increases with higher positions of the water table. During dry and drought periods the ground water provides the total flow of Whiteoak Creek as well as evaporation and transpiration losses. As stated earlier in this chapter it is estimated that the low flow of Whiteoak Creek above the settling basin would be about 135 gallons per minute, equivalent to a runoff of about .3 sec.-ft. for the contributing portion of the watershed. During flood periods the ground-water discharge would be much greater but would constitute a smaller percentage of the total flow. After any flood, some water from the pools left by the receding streams would be added to the aquifer in part to be later discharged as seepage in the stream banks.

Reconnaissance surveys have shown that contamination does exist on the flood plains and in the stream channel of Whiteoak Creek. The contamination in the stream tends to be built up on small stream deposits, such as sand bars and along stream meanders.

From a study of Plate 13, it appears that, with the exception of the area near the west end of the "burial ground" any contamination of the ground water in the X-10 area will be restricted to the Whiteoak Creek watershed. Ground water moving down gradient in the X-10 area, contributes to the flow of Whiteoak Creek, and since the creek discharges into Whiteoak Lake any contaminated ground water surviving the filtering action of the soil, the time element of slow underground flow, and the time element of more rapid surface flow, is eventually added to the contamination already present in the waters of Whiteoak Lake.

The exception to this pattern of ground-water movement is found at the westernmost portion of the present "burial ground." Here the water-table contour map indicates the existence of a ground-water divide between Whiteoak Creek drainage and Raccoon Creek drainage. This divide possibly shifts toward the east during dry periods and toward the west during wet periods. It would be possible, therefore, for contamination to enter the Raccoon Creek drainage during dry periods. If the "burial ground" is extended to the west, then the period during which contamination could enter the Raccoon Creek drainage system would be lenthened.

CHEMICAL QUALITY OF GROUND WATER IN THE X-10 AREA

Table 3 lists chemical analyses of water from test wells in the X-10 area and also gives analyses of ground water from adjacent areas. The analyses apparently are typical of water from these formations in other parts of the Valley and Ridge province, and exhibit a high degree of uniformity, with the exception of the analysis for well No. 26. It is believed that the difference in the quality of water in well 26 results from its being drilled in an area of artificial fill consisting of cinders and other material containing sulfate. The radiometric determinations included in Table 3 provide important background data concerning the natural radium content of ground waters of the area. However, this information has no present bearing on the contamination problem since the contaminating material does not contain radium.

CHAPTER VI. FINDINGS WITH RESPECT TO UNDERGROUND CONTAMINATION

GENERAL STATEMENT

Several methods have been used to determine whether or not the ground water and rock formations in the Oak Ridge National Laboratory (X-10) area have been contaminated by radioactive wastes. Some procedures are being continued and additional ones are contemplated. The following types of examination and experimentation have already been made:

1. Air-pressure test of drill hole No. 1 which runs obliquely beneath the main settling pond, to ascertain inter-connections, if any, between the contaminated waters of the pond and the rock beneath.

2. Assays for gross beta activity of drilling sludge samples collected during core drilling of the 51 exploratory wells.

3. Assays for gross beta activity of ground-water samples from drill holes.

4. Radiochemical analysis for fission products of water from drill holes.

5. Drill-hole radiologging with a water-proof submergible counter probe.

6. Chemical analyses of water samples from 44 exploratory holes.

AIR-PRESSURE TEST OF DRILL HOLE NO. 1

Hole No. 1 was drilled obliquely, at an angle of 55 degrees, beneath the settling pond starting at the dike on the southeast side and running northwestward beneath the pond. The rock strata at the site dip at an angle of approximately 35 degrees in a direction S 32° E. The hole was drilled in a direction N 32° W so as to cut the rock layers at right angles to the bedding. It pierces 300 feet of strata, starting in unit "G" of the Chickamauga formations and extending 4.4 feet into unit "F." Thus, 295.6 feet of the hole cuts through the beds of gray "nodular" limestone of the unit "G." These rock layers extend upward to the bottom of the settling pond. (See Plate 2.)

After hole No. 1 was drilled, it was pumped by the air-lift method to remove the drilling water. Likewise, subsequent holes were pumped immediately after drilling and then allowed to recover their natural ground waters. However, during the pumping operation of hole No. 1, small air bubbles were noticed on the surface of the pond along a line above that of the drill hole, suggesting that air was leaking through the rocks into the overlying settling pond. At a later date the hole was pressure tested, at five-foot intervals, under 100 pounds of air pressure, to determine, if possible, where the strata were leaking. The test showed that within the first 50 feet of the well, air escaped easily from four of the five-foot zones. At one point, escape was so vigorous as to create prominent turbulence or "boils" rather than small bubbles in the pond waters. Thruout the remainder of the hole the test revealed no prominent escape routes, although small bubbles appeared on the surface along the line of the hole, as well as along the direction of strike at right angles to it. There was a delay of some several minutes in the arrival of these small bubbles from the time the air pressure was applied, suggesting slow passage of air through the rock. The testing showed that the limestone was far from impermeable and that, on the other hand, a free connection did exist between the pond and the bed rock many feet beneath.

This suggests that, under proper hydrologic conditions, contaminated water from the pond could move downward to the ground waters beneath by the route of solution channels in the limestone.

ASSAYS OF SLUDGE AND WATER SAMPLES FROM DRILL HOLES

During the drilling of the exploratory wells sludge samples were collected and assayed for gross beta activity. Tap water was used for the core drilling. From hole No. 1 which runs obliquely beneath the settling pond 61 sludge samples were collected, mostly at five-foot intervals. From 25 other holes a total of 60 sludge samples were collected, most of them from the soil overburden and the immediately underlying bed rock. Sludge samples were not taken at regular depth-intervals during drilling of the bed rock, except in the case of hole No. 1. After each well was drilled it was pumped by air lift method to remove the drilling water. After filling with ground water, it was pumped a second time and allowed to fill again. Then fresh water samples, free from sludge, were taken by means of a hand pump. These were also assayed for gross beta activity. Forty-nine water samples were taken from 45 different drill holes. Assays of the sludge and water samples were made by the Area Monitoring Unit of the Health Physics Division of the Oak Ridge National Laboratory. Results were given in two reports, namely, Report No.. MON-168-50, by W. D. Cottrell and R. G. Lawler, under date of July 21, 1950, and supplemental Report No. MON-196-50, December 8, 1950, by R. G. Lawler.

As reported by Cottrell and Lawler "the assays were made by reducing to dryness small volumes of sludge and/or water in aluminum sample dishes and counting in a standard end-window beta counter at approximately 10% geometry. The results were treated statistically using the 0.05 level of significance.......

"Volumetric methods were used in sample preparation. Since the amount of solid material in the sludge varied widely from sample to sample, and since the samples were not weighed to determine the amount of solid material in each individual sample, an estimate of the average solid content per sample was made. This estimate, 0.3 gms. per sample, was used in making calculations of the radioactive content of the sludge in terms of microcuries of activity per gram of dry sludge. Because of this the specific activity value of any individual sample, in terms of μc/gm, may be somewhat in error. However, the average of all samples should give a fairly reliable idea of the order of magnitude of the activity involved."

See table 4 for the tabulation of results of assays of all samples of both sludge and water, as submitted by R. G. Lawler in his Report No. MON-196-50:

It will be observed from inspection of the above table that the activity levels of the 121 sludge samples ranged zero to a maximum of 16.5×10^{-5} μc/gm, and that the levels of the 49 water samples ranged from zero to 23.8×10^{-7} μc/cc. That twenty-three sludge samples showed activity of 3.0×10^{-5} μc/gm or more, with an average of 5.4×10^{-5} μc/gm, was considered significant by Cottrell and Lawler, in their report MON-168-50, who wrote: "the magnitude of the results on sludge samples indicates a level of radioactivity above that which might be expected from the natural radioactivity of the soil."

Cottrell and Lawler also noted that 19 of the water samples showed activity of 6.0×10^{-7} µc/cc or more, with an average of 15×10^{-7} µc/cc and concluded that "this value is quite high when compared to a value of 2.5×10^{-8} µc/cc observed in waters of the Clinch River" and that "this is indicative of radioactivity in excess of that observed to be occurring naturally in this area."

Seventeen drill holes produced sludge samples with activity levels of 3.0×10^{-5} µc/gm or more, namely holes Nos. 1,2,4,7,10,11,12,13,14,17, 18,26,27,28,30,35 and 38. Reference to Plates 2 or 13 which give the locations of all the drill holes, shows that those with higher activity levels are situated, with two exceptions, around the main settling pond and along Whiteoak Creek. This suggests contamination from seeping waters from the pond and/or the creek. The exceptions are holes No. 38 (the one with highest of all activity among the sludge samples) and No. 28. The first of these is located a few feet northwest of the north tank farm, and thus raises the question of a leak or spill at sometime in the liquid waste disposal system, while the second is at the edge of a small, abandoned burial ground.

The 19 drill holes which produced water samples with activity higher than 6.0×10^{-7} µc/cc are: Nos. 1,4,8,10,12,13,17,22,23,26,27,30,31,34, 35,36,37,40 and 42. (See Plates 2 and 13.) Most of these. like those involving sludge samples, are located around the settling pond and along Whiteoak Creek. Six of them, holes nos. 34,35,36,37,38,40, are located northwest of the settling basins, in the vicinity of the tank farms and other units of the waste disposal system. Two holes, Nos. 22 and 23, are located next to the main burial ground. It is significant the holes which are located at considerable distance from the settling pond and Whiteoak Creek are the ones which produced water samples showing least or no activity. Reference is made particularly to holes Nos. 24,25,43,44,45, 46,47,48, and 49.

RADIOCHEMICAL ANALYSES OF WATER FROM DRILL HOLES

Two samples of water from drill hole No. 1 were analyzed for fission products. This hole is the one which runs obliquely beneath the settling pond and which revealed, thru air-pressure test described above, connection with the contaminated waters of the overlying pond. Results of the analyses were reported by A. H. Emmons of the Waste Disposal Research Section, Health Physics Division of the Oak Ridge National Laboratory, in a memorandum under date of June 7, 1950.

Water sample "A" consisted of 45 gallons collected from hole No. 1 on April 6, 1950, and sample "B" consisted of 14.7 gallons collected on April 20, 1950. Concerning analysis procedure, Emmons wrote: "one ml. of aluminum sulfate solution (821 g/gallon H_2O) was added for each gallon of sample. The pH was adjusted to 7.0 $\pm$ 0.1 with Na_2CO_3 and the sample was agitated for 20 minutes. The $Al(OH)_3$ floc formed was allowed to settle for 12 hours and the clear supernate was siphoned off and discarded. The floc was then washed from the mixing basin (a 55 gallon drum), further concentrated by centrifugation, dissolved in 6 M HNO_3 and filtered. (At this point there was a distinct evolution of hydrogen sulfide which will be mentioned later). The HNO_3 filtrate was counted for gross beta activity and the residue was ignited, mounted and counted. The residue contained the majority of the beta activity present in the sample so an absorption curve was run on it which indicated a strong beta (Ruthenium^{106}; $\beta^- > 3$ mev).

"A qualitative group separation was performed on the filtrate to determine what the soluble beta component was. A cerium analysis, and a study of the growth of the Pr^{144} 17 minute daughter back into the cerium, indicated the presence of cerium^{144}. Any other fission products present were below the detection limits of this method. The efficiency of scavengering of trace elements from large volumes of water by flocculation methods varies with the elements sought. Tracer experiments indicate a carrying efficiency of approximately 50% for ruthenium and 60% for cerium on $Al(OH)_3$ floc."

Results of the analyses were tabulated by Emmons as follows:

"Sample A, 45 gallons, 5-6-50

Total gross beta present = 664 c/m*

Total Ruthenium^{106} identified = 430 c/m

Total Cerium^{144} identified = 119 c/m

Percent of total gross activity identified = 82%

Correcting for carrying efficiencies, the total Ru and Ce present and identified = 1178 c/m. This is 3.1×10^{-8} μc/cc which means the water, from the standpoint of activity, is potable.

Sample B, 14.7 gallons, 5-20-50

Total gross beta present = 50 c/m

No positive identification possible"

DRILL-HOLE RADIOLOGGING WITH A COUNTER PROBE

Upon completion of the drilling of the 51 exploratory wells, a program of radiologging was begun by the Area Monitoring Unit of the Health Physics Division of the Oak Ridge National Laboratory. The work has been carried on intermittently and has not been completed. A report of progress was prepared by J. M. Garner under date of March 16, 1951, in which the equipment and procedure used, and findings to date, were summarized.

Equipment and Procedure

The following is quoted from the Garner report: "The equipment used consists of a thin-walled glass Geiger-Mueller Tube, with pre-amplifier and impedance matching network, housed in bakelite tube $1\frac{1}{2}$" outside diameter with 1/16" wall thickness, connected by about 310 feet of cable to a counting rate meter and Esterline-Angus recorder.

"Thirty radio-logs on 23 wells were made by lowering the probe by hand and taking measurements for radioactivity at one yard intervals. Where an increase of radiation was detected the region was explored in one foot intervals. On November 11, 1950 a motor-driven cable reel was put in use. This device will lower the detector described above at a pre-determined rate and give a continuous log of the well. When the detector reaches a pre-set depth the equipment is automatically cut off. Thus the equipment does not require constant attention of an operator. Thirty logs on 14 wells have been made with this equipment."

Observations and Findings

At the time of the Garner report 30 drill holes had been logged at least once. The detected radiation, expressed in counts per minutes at various depths, is given in Table 5. The readings for a given drill hole at any particular depth which exceed the average for other holes at the corresponding depth are pointed out by an asterisk (*).

Concerning observations and conclusions, the following is copied from the Garner report:

"Cosmic radiation, natural radioactivity of the geological formation, and the radioactivity of ground waters contribute to the measured counts per minute. No attempt has been made to correct for cosmic radiation and the radiation from stratigraphic layers. A beta GM tube is now being developed for use in the detector unit which will increase the sensitivity to radioactivity in the ground waters. While specific conclusions cannot be drawn from the data, without information for interpretation of the effect from cosmic radiation and natural radioactivity of geological strata, some general observations are indicated.

"From examinations of the radio-log and the geological log of well number 1 it appears that fractured rock at about 86 foot depth permits interconnection of this well with the settling basin. The radio-log of well number 17 suggests seepage into this well from either the east or west pond or the settling basin which surrounds it or a highly contaminated surface drain near-by.

"The intensity of the radiation detected in wells numbers 38 and 39 cannot be explained by any known or suspected contamination of the ground water by natural percolation from the liquid waste disposal system. The findings of these wells which are located at considerable elevation above the waste disposal system suggests the desirability of searching for a broken "hot drain" in this vicinity as a possible source of contamination.

"The intensity of radiation in the bottom of wells number 1 and 3, which just penetrated a maroon siltstone formation, as well as radon determinations made on samples of the siltstone confirm the prediction that the natural radioactivity of the siltstone is higher than the natural radioactivity of the overlying limestone. The intensity of the activity in well number 50 cannot be explained on the basis of present knowledge. It is located on the opposite side of the valley from the disposal system and is at a higher elevation. Other wells in which there appears to be some elevation of radiation intensity above the general average include numbers 5,7,19,28,29,33,35, and 36."

CHAPTER VII. RECOMMENDATIONS AND CONCLUSIONS

FURTHER INVESTIGATIONS NEEDED

It is recognized that the investigations of the ground-water and geologic conditions at the X-10 site of the Oak Ridge National Laboratory have not been completed, that some of the findings are not conclusive, and that some problems are still unsolved. Major objectives of the studies, however, have been attained. Findings to date, with respect to underground contamination, are summarized in Chapter VI. These suggest the need for continuation of some of the studies that have been started.

The following are proposed:

1. That there be radiochemical analyses of water drawn from drill holes 1,17,28,38 and 50.
2. That radiologging of all drill holes be continued and repeated periodically.
3. That studies be made of the natural radioactivity of rock samples, obtained from areas known to be uncontaminated, of the same geologic formations as those in the exploratory wells, for purposes of comparing with the findings obtained by radiologging of the drill holes.
4. That periodic check on the water levels in all exploritory wells be continued thru the year 1952, or longer, for the purpose of ascertaining seasonal and non-periodic variations in the position of the water table, and that study of other pertinent matters relevant to hydrologic conditions be continued.

5. That consideration be given to the possibility of a leaking or broken "hot drain" in the vicinity of drill holes Nos. 38 and 39 where an abnormally high intensity of radiation was detected by the counter probe. (Discussed in Chapter VI.)

6. That drill hole No. 50 be given special study with the view of determining, if possible, the cause of its high intensity of activity which cannot be explained on the basis of present knowledge. (Discussed in Chapter VI.)

7. That there be pumping tests on one or more exploratory wells to determine, if possible, (a) the coefficient of storage of ground water, and (b) the transmissibility of the rocks.

GENERAL RECOMMENDATIONS

With respect to future expansions and operations at the Oak Ridge National Laboratory, the following are recommended:

1. That geologic investigations precede the selection of sites for new buildings and other operations.

2. That no new settling ponds, for the hold-up of radioactive liquid wastes, be constructed in the limestone belt of Bethel Valley (the present site of X-10).

3. That all future burial of contaminated solid waste be in the Conasauga shale belt of Melton Valley (discussed in the following section).

PROPOSED NEW BURIAL GROUND

At the Oak Ridge National Laboratory disposal of radioactive solid wastes and contaminated equipment and materials 's by burial in the ground. The practice is simply to remove the soil down to bed rock, generally less than 15 feet deep, dump the wastes into the excavation and then cover with the soil, except in the case of alpha-contaminated materials which are first covered with concrete before burial. When this study was begun three different burial sites had been used. The first two sites to be used had been abandoned and their locations left none too-clearly defined. The one which was in current use was initiated in May 1946. It lies in Bethel Valley at a distance of some 3000 feet southwest of the present boundary of the X-10 plant site. (See Plate 2.) In four and one half years this burial ground area has grown in size to five and one-half acres. In addition to the radioactive and contaminated solid wastes from the operations at the Oak Ridge National Laboratory, there was also being received for burial at this site wastes from other AEC-project producers as well as from users of AEC-distributed isotopes. The steady increase in customers as well as in quantity and variety of waste to be disposed, is steadily magnifying the problem of burial at the Oak Ridge National Laboratory, and calls for cautious consideration of long-range burial operations.

The vulnerability of the burial ground site with respect to contamination of migrating underground waters was pointed out by Stockdale during the initial states of this study. Concern for the matter, especially by the Health Physics Division of the Oak Ridge National Laboratory, led to a field conference on May 19, 1949. The following persons participated:

Edward McCrady, Senior Biologist, Office of Research and Medicine, Atomic Energy Commission, Oak Ridge

T. H. J. Burnett, Health Physics Division, Oak Ridge National Laboratory

H. J. McAlduff, Health Physics Division, Oak Ridge National Laboratory

Paris B. Stockdale, Head of the Department of Geology-Geography, University of Tennessee, Knoxville

Four possible burial ground sites, tentatively recommended by Stockdale, were visited and inspected in the field. Under date of May 25, 1949, a written memorandum was submitted by Stockdale to the Office of Research and Medicine of the Atomic Energy Commission at Oak Ridge pointing out the potential hazards of the present burial ground and making recommendations on the selection of a new and preferred site.

At a conference held on August 3, 1949, the whole matter involving selection of a new burial ground site was reviewed before the following representatives of the Oak Ridge National Laboratory: D. C. Bardwell, L. B. Emlet, E. J. Murphy, A. M. Weinberg, Forrest Western, and E. J. Witkowski. Stockdale again summarized the geologist's viewpoints as regards the potential hazards at the currently-used burial ground, and also indicated that, from a long-range viewpoint, usable space at the site is quite limited by outcropping bedrock so that, eventually, a more commodius site must be chosen.

In a previous chapter in this report it has been pointed out that the Bethel Valley burial ground lies upon unit "G" of the Chickamauga limestone where there exists the possibility of radioactive contamination of underground waters and the uncontrolled migration of such to unknown distant sites.

This risk results from the fact that the underlying bed rock is limestone which is susceptible to underground solutions and to the development of small voids with consequent increase in permeability and free movement of ground waters which may have been contaminated from downward percolation of meteoric waters through the burial ground. That migration of such contamination has taken place is shown by the probing of drill holes located outside the boundaries of the burial ground. This has been discussed in the preceding chapter of this report.

From the viewpoint of the geologist, a preferred site for burial of radioactive solid wastes and contaminated materials in the Oak Ridge vicinity would be at a place underlain by shale. Such rock is generally quite impermeable and is not subject to solution which might lead to the development of underground channels to permit the free transfer of ground waters. In the Oak Ridge area the most extensive geologic formation which is composed of shale is the Conasauga. The formation is at least 1500 feet thick. Where weathered, it forms a soft clay soil which can be easily handled with power shovels.

In the general vicinity of the X-10 unit of the Oak Ridge National Laboratory there are two significant, broad belts of the Conasauga shale. One is situated on the northwest side of Bear Creek Valley, between Pine Ridge and Chestnut Ridge. The other is between Haw Ridge and Copper Ridge, to the southeast of the X-10 site. The latter belt has the advantage of being accessible from the Laboratory without travel over any of the main roads. It can be reached by going through Whiteoak Creek gap which cuts through Haw Ridge just south of the Laboratory. A second advantage lies in the fact that any surface waters which might become contaminated at a burial site would drain directly into the already-contaminated lake.

The specific site to be selected within the belt of Conasauga shale would depend upon several factors. One would be the nature of the topography -- a fairly flat area would be favored, preferably at a comparatively low level. Another would be the amount of area needed. The depth of weathering must be considered since such would determine ease and depth of excavation.

A site which is most favored, and which has been recommended by Stockdale on the basis of an examination of the surface shale and the topography, lies southeast of Haw Ridge immediately northwest of the lower end of the Whiteoak Lake, approximately one and one half miles south-southwest of the X-10 plant site, where there is a large acreage of comparativly flat topography underlain by shale which is soft and well-weathered and where the ground is barren of trees. (See Plate 1.) It is in part a remnent of a gravel-covered terrace. If but a small site were needed several places might be picked within closer range of the Laboratory and within the Pumpkin Valley memoer of the Conasauga shale belt.

Steps have recently been taken to abandon the Bethel Valley burial ground and to establish burial sites in the Conasauga shale belt southeast of Haw Ridge, discussed above.

GENERAL CONCLUSIONS

That some radioactive contamination occurs in the underground waters and the rock formations at the X-10 site of the Oak Ridge National Laboratory has been discussed in the preceding chapter of this report. Most of the detected contamination came from the liquid waste disposal system; doubtful contamination from the Bethel Valley burial ground (recently abandoned). Since by the very nature of the disposal system, discussed in Chapter I, underground contamination seemed inevitable, important objectives at this study were to determine the conditions of the underlying rock formations and the resulting form of the water table and the movement of ground waters as potential carriers of radioactive contamination. In this connection, therefore, an important question to be settled was whether or not simple water-table conditions, or artesian conditions prevail underground.

Altho the bedrock at the X-10 site of the Laboratory is predominantly limestone, the program of core drilling revealed that the rock is at present apparently devoid of sizeable underground solution channels, or caverns, which conceivably might have existed and were feared, and which might have exerted significant control over the direction and amount of flow of ground waters. Instead, the limestone is comparatively "tight," possessing abundant, closely-spaced, closed fractures and joints with only an occasional solution channel of small size.

Studies by the Ground Water Branch of the U. S. Geological Survey, as reported by G. D. DeBuchananne in Chapter V of this report, reveal that "by its close correlation with the topography and surface drainage, ground water occurs under water-table rather than artesian conditions." (See

Plate 13.) DeBuchannane wrote further: "thus ground-water discharge contributes to the base flow of the surface streams in this area, and ultimately augments the flow of the Clinch River...... In general, the water table is subdued replica of the land surface, rising slightly below the hills but occupying position closer to the land surface in the valleys." Under these conditions, fortunately, all drainage at and below the surface today apparently converges to empty ultimately into the intended liquid waste disposal system of Whiteoak Creek and White Lake. Thus, any ground water recharge which might come from the operations of the liquid waste disposal system at X-10, even tho contaminated, would be held up for awhile underground and would finally emerge into the intended disposal system, thus assuring no hazard to areas not already under control or unknown. An exception to this situation, perhaps relatively insignificant, occurs at the west end of the recently-abandoned burial grounds where the ground water on the west side of a ground-water divide will flow toward the west into Racoon Creek drainage rather than into Whiteoak Creek. However, but a small amount of area is involved and there is yet no proof of underground contamination.

Table 3--Analyses of Naturally Occurring Waters in the Vicinity of the X-10 Area of the Oak Ridge National Laboratory

(Chemical Analyses by the U. S. Geological Survey)
(Radiometric Analyses by the National Bureau of Standards)
Chemical Analyses in Parts Per Million

Wells Owned by A. E. C. in the X-10 Plant Site Area
(for location see Plate 13)

Well Number	Date of Collection	Silica (SiO_2)	Zinc (Zn)	Aluminum (Al)	Copper (Cu)	Manganese (Mn)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Dissolved Solids	Total Hardness as ($CaCO_3$)	Specific Conductance (micromhos at 25° C.)	pH	Color	Radium content in gram/liter (x 10^{-12})
1	2/28/50	8.2	0	.3	0	0	.06	46	21	61	2.6	0	356	24	10	.5	.2	0	337	201	591	7.8	5	0.79
2	12/30/49	12	0	.2	0	0	.02	40	24	46	4.6	0	329	26	3.5	.6	.1	0	313	198	538	7.5	6	0.70
3	3/30/50	11	0	.2	0	0	.06	117	27	17	1.8	0	476	40	2.4	.1	.2	0	445	403	759	7.7	1	0.75
4	1/12/50	9.0	1.6	.7	0	—	.04	88	13	20	3.4	0	352	15	4.4	.1	.5	0	325	273	574	5.9	5	0.76
5	2/28/50	11	0	.2	0	0	.06	54	21	31	3.4	0	340	13	1.4	.4	.7	0	287	221	515	7.8	3	0.86
6	1/19/50	11	.5	.8	0	—	.06	72	20	43	3.3	0	368	38	11	.7	.3	0	376	262	652	7.4	15	0.90
7	1/19/50	11	0	.5	0	—	.04	87	17	17	.6	0	350	28	8.6	.1	.4	0	337	278	582	7.4	5	0.36
8	1/26/50	10	0	.6	0	—	.04	51	27	41	1.7	0	374	21	5.2	1.1	.1	0	324	238	577	7.5	5	1.30
9	2/28/50	4.4	0	0	0	—	.12	63	6.5	6.5	1.0	0	232	6.7	1.5	.1	.8	0	186	184	337	7.9	5	0.81
10	1/31/50	11	0	.4	0	—	.03	83	18	12	1.5	0	350	14	11	.2	.1	0	302	281	548	7.3	3	3.97
11	1/26/50	11	0	.2	0	—	.03	63	26	23	3.2	0	360	11	10	.4	1.1	0	310	264	563	7.4	5	0.70
12	1/31/50	2.8	0	.5	0	—	15.	39	14	11	3.3	0	178	32	5.2	.3	.1	0	189	155	342	7.6	5	1.15
13	3/30/50	2.8	0	0	0	0	.08	72	5.5	3.1	2.6	0	224	16	3.8	.1	3.6	0	213	202	387	7.6	2	0.91
14	2/7/50	3.8	0	.7	0	—	.16	65	4.0	6.6	1.3	0	210	13	2.9	.1	1.1	0	201	179	353	7.4	10	1.33
15	1/31/50	6.4	0	.4	0	0	.06	63	22	5.7	1.1	0	264	24	10	.2	1.2	0	255	248	464	7.8	1	1.33
16	3/30/50	9.4	0	.2	0	0	.06	58	15	22	3.0	0	244	24	13	.2	.4	0	245	206	444	7.9	3	0.77
17	2/7/50	4.0	0	1.4	0	—	.26	45	3.6	7.6	1.5	0	148	17	3.1	.2	1.6	0	158	127	274	7.3	3	0.99
18	2/7/50	11	0	.7	0	—	.07	56	24	37	1.6	0	345	5.4	11	.4	.1	0	312	238	569	7.4	5	0.82
19	Well not sampled																							
20	3/30/50	9.2	0	0	0	0	.04	53	17	19	2.2	0	256	25	4.5	.4	.2	0	241	202	437	7.8	8	0.97
21	3/30/50	15	0	.2	0	—	.02	62	19	15	3.1	0	300	13	2.1	.2	.2	0	268	232	480	7.7	3	0.44
22	3/30/50	9.2	0	.1	0	—	.02	63	18	2.8	1.2	0	260	8.8	5.6	.1	.0	0	234	231	433	7.5	2	0.44
23	3/30/50	3.8	0	.1	0	—	.03	106	12	5.0	.9	0	325	23	13	.1	.1	0	339	314	593	7.2	4	1.23
24	4/6/50	9.8	0	.7	0	—	.16	21	10	96	3.2	0	330	25	6.0	1.6	1.6	0	335	94	562	7.9	5	—
25	Well not sampled																							
26	4/6/50	11	0	2.2	0	—	.04	183	28	46	2.1	0	301	376	30	.3	1.5	0	880	572	1200	6.8	2	—
27	3/30/50	7.0	0	0	0	—	.02	86	8.0	7.8	1.5	0	266	33	6.9	.1	.9	0	288	248	498	7.0	5	0.64
28	3/30/50	9.8	0	0	0	—	.04	86	18	19	4.3	0	281	74	14	.1	.8	0	369	268	613	7.4	4	0.44
29	3/30/50	11	0	.1	0	—	.04	17	9.7	4.0	7.4	0	106	7.8	1.0	.1	.1	0	105	82	191	8.1	5	0.54
30	4/6/50	11	0	1.3	0	—	.07	59	25	37	2.8	0	342	27	7.6	.5	.9	0	326	250	579	6.4	5	—
31	4/6/50	13	0	1.0	0	—	.04	61	31	8.0	3.2	0	336	17	1.8	.2	1.4	0	295	280	522	6.3	3	—
32	3/30/50	5.2	0	.2	0	—	.03	92	12	4.3	1.0	0	303	32	1.6	.1	.1	0	302	279	526	7.3	7	—
33	4/6/50	9.2	0	1.3	0	—	.17	56	15	72	2.0	0	374	18	14	.4	.6	0	355	201	625	6.7	7	—
34	4/6/50	7.6	0	1.0	0	—	.04	94	6.5	2.2	.6	0	294	19	2.6	.0	1.6	0	273	261	487	6.7	1	—
35	4/6/50	11	0	.7	0	—	.04	117	6.6	2.7	.7	0	382	6.5	3.9	.0	.2	0	325	319	586	6.9	5	—
36	4/6/50	9.6	0	1.3	0	—	.02	99	12	2.1	.8	0	298	26	13	.0	4.1	0	311	296	552	6.7	2	—
37	4/6/50	11	0	.8	0	—	.05	73	27	17	2.0	0	344	33	6.6	.3	0.2	.1	330	293	576	7.5	1	—
38	4/6/50	15	0	1.0	0	—	.12	83	5.5	3.0	.5	0	270	4.9	6.4	.0	.1	0	255	230	438	7.4	7	—
39	Well not sampled																							
40	4/6/50	10	0	.8	0	—	.05	123	17	6.7	1.2	0	408	43	3.2	.1	.2	0	393	377	680	7.3	3	—
41	Well not sampled																							
42	4/6/50	6.8	0	.3	0	—	.03	83	28	5.5	2.6	0	339	47	1.1	.2	.9	0	343	322	595	7.3	4	—
43	4/6/50	9.0	0	.1	0	—	.07	77	9.4	5.4	1.2	0	281	4.0	2.6	.1	.7	0	244	230	445	7.4	3	—
44	4/6/50	11	0	0	0	—	.05	96	44	4.2	2.8	0	452	45	1.4	.2	1.0	0	435	420	745	7.2	4	
45	4/6/50	10	0	.5	0	—	.06	61	14	9.5	1.7	0	270	5.3	1.2	.2	.7	0	230	210	419	6.6	2	—
46	4/6/50	11	0	.3	0	—	.24	34	16	54	3.0	0	308	8.9	2.2	.8	1.8	0	268	151	473	6.3	3	—
47	4/6/50	6.4	0	1.3	0	—	.03	64	11	6.4	1.2	0	238	17	1.5	.1	1.2	0	216	205	396	6.5	1	—
48	Well not sampled																							
49	4/6/50	7.8	0	1.6	0	—	.16	70	6.2	2.6	1.2	0	218	15	1.8	.0	.1	0	203	200	365	7.6	2	—
50	Well not sampled																							

957 087

Table 3--Continued

Well Number	Date of Collection	Silica (SiO_2)	Zinc (Zn)	Aluminum (Al)	Copper (Cu)	Manganese (Mn)	Iron (Fe)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Carbonate (CO_3)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Phosphate (PO_4)	Dissolved Solids	Total Hardness as ($CaCO_3$)	Specific Conductance (micromhos at 25°C.)	pH	Color	Radium content in gram/liter (x 10^{-12})
White Oak Creek, sampled about 300 feet upstream from settling pond																								
	8/9/49	—	—	—	—	—	0.18	62	14	37(Na+K)	—	0	38	242	6.2	—	1.4	—	—	212	504	6.2	—	—
Wells Owned by A. E. C. and U. T. Experimental Farms																								
1-501	8/8/49	—	—	—	—	—	.06	33	21	7.8(Na+K)	—	0	215	2	3.5	—	3.1	—	—	169	336	7.45	—	—
1-502	8/8/49	—	—	—	—	—	.03	75	18	40 (Na+K)	—	0	375	12	20	—	1.2	—	—	261	639	7.3	—	—
1-503	8/8/49	—	—	—	—	—	.19	58	30	11 (Na+K)	—	0	331	13	3.8	—	1.0	—	—	268	519	7.4	—	—
Privately Owned Wells Southwest of White Oak Lake Across Clinch River																								
73-1 1/	9/19/49	7.8	4	1.2	0	—	.05	87	6.5	16	12	0	260	16	41	0	8.2	.0	324	244	569	7.1	7	1.43
73-506 2/	9/19/49	7.4	0	.4	0	—	.12	23	7.8	16	20	0	122	14	18	0	10	.3	199	69	338	6.9	2	1.39
73-510 3/	9/19/49	13	0	.2	0	—	1.10	27	22	3.1	3.6	0	164	4.7	10	0	10	.0	192	158	335	6.8	4	0.93

1/ Owner: P. E. Waller, Lenoir City, RFD #2, Depth: 24 feet. Formation: Conasauga shale.

2/ Owner: W. H. Hensley, Lenoir City, RFD #2, Depth: 29 feet. Formation: Rome.

3/ Owner: M. Waller, Lenoir City, RFD #2, Depth: 42 feet. Formation: Conasauga shale.

Table 4

ASSAYS OF SLUDGE AND WATER SAMPLES FROM DRILL HOLES

A. Sludge Samples

No.	Sample Number	Sample Depth	Sample Size	Net Cts/ Minute	Cts/Min/ ml	~ 10^{-5} µc/gm
	1	5 ft.	10 ml	0	0.0	0.0
	2	10 "	10 "	3	0.3	0.4
	3	15 "	10 "	2	0.2	3.0
	4	18 "	5 "	0	0.0	0.0
	5	23 "	5 "	0	0.0	0.0
	6	28 "	10 "	1	0.1	1.5
	7	33 "	10 "	2	0.2	3.0
	8	38 "	10 "	1	0.1	1.5
	9	43 "	10 "	0	0.0	0.0
	10	48 "	10 "	1	0.1	1.5
	11	53 "	10 "	1	0.1	1.5
	12	58 "	10 "	0	0.0	0.0
	13	63 "	10 "	0	0.0	0.0
	14	68 "	10 "	1	0.1	1.5
	15	73 "	10 "	0	0.0	0.0
	16	78 "	10 "	0	0.0	0.0
	17	83 "	10 "	0	0.0	0.0
	18	88 "	10 "	0	0.0	0.0
	19	93 "	10 "	2	0.2	3.0
	20	98 "	10 "	0	0.0	0.0
	21	103 "	10 "	1	0.1	1.5
	22	108 "	10 "	1	0.1	1.5
	23	113 "	10 "	0	0.0	0.0
	24	118 "	10 "	1	0.1	1.5
	25	123 "	10 "	0	0.0	0.0
	26	128 "	10 "	0	0.0	0.0
	27	133 "	10 "	2	0.2	3.0
	28	138 "	10 "	2	0.2	3.0
	29	143 "	10 "	0	0.0	0.0
	30	148 "	10 "	0	0.0	0.0
	31	153 "	10 "	1	0.1	1.5
	32	158 "	10 "	1	0.1	1.5
	33	163 "	10 "	0	0.0	0.0
	34	168 "	10 "	0	0.0	0.0
	35	173 "	10 "	1	0.1	1.5
	36	178 "	10 "	0	0.0	0.0
	37	183 "	10 "	1	0.1	1.5
	38	188 "	10 "	1	0.1	1.5
	39	193 "	10 "	1	0.1	1.5
	40	198 "	10 "	0	0.0	0.0
	41	203 "	10 "	1	0.1	1.5
	42	208 "	10 "	1	0.1	1.5
	43	213 "	10 "	1	0.1	1.5
	44	218 "	10 "	1	0.1	1.5
	45	223 "	10 "	0	0.0	0.0
	46	228 "	10 "	1	0.1	1.5
	47	233 "	10 "	0	0.0	0.0
	48	238 "	10 "	0	0.0	0.0

Sludge Samples Cont'd.

ole No.	Sample Number	Sample Depth	Sample Size	Net Cts/ Minute	Cts/Min/ ml	~10 µc/g
1	49	243 ft.	10 ml	0	0.0	0.0
1	50	248 "	10 "	2	0.2	3.0
1	51	253 "	10 "	1	0.1	1.5
1	52	258 "	10 "	0	0.0	0.0
1	53	263 "	10 "	0	0.0	0.0
1	54	268 "	10 "	0	0.0	0.0
1	55	273 "	10 "	0	0.0	0.0
1	56	278 "	10 "	1	0.1	1.5
1	57	283 "	10 "	0	0.0	0.0
1	58	288 "	10 "	1	0.1	1.5
1	59	293 "	10 "	1	0.1	1.5
1	60	298 "	10 "	1	0.1	1.5
1	61	300 "	10 "	1	0.1	1.5

Hole No.	Sample Number	Sample Depth	Sample Size	Net Cts/ minute	Cts/Min/ ml	~10-5 uc/gm
2	1	6' - 10"	10 ml	2.0	0.20	3.0
2	2	9' - 10"	10 "	2.0	0.20	3.0
2	3	14' - 2"	5 "	1.0	0.20	1.5
2	4	19' - 2"	5 "	0.0	0.00	0.0
2	4A	9' - 0"	200 "	4.0	0.02	6.0
2	5	20' - 0"	10 "	0.0	0.00	0.0
3	1	81' - 8"	10 "	0.0	0.00	0.0
4	1	5' - 0"	10 "	0.0	0.00	0.0
4	2	10' - 0"	20 "	2.0	0.10	3.0
4	2A	10' - 0"	20 "	3.0	0.15	4.5
4	4	41' - 0"	10 "	0.0	0.00	0.0
4	5	Special	10 "	1.0	0.10	1.5
6	1	5' - 0"	5 "	0.0	0.00	0.0
6	2	10' - 0"	5 "	0.0	0.00	0.0
6	3	13' - 0"	10 "	0.0	0.00	0.0
7	1	5' - 0"	5 "	2.0	0.40	3.0
7	2	15' - 0"	5 "	0.0	0.00	0.0
8	1	5' - 0"	5 "	1.0	0.20	1.5
8	2	10' - 0"	5 "	1.0	0.20	1.5
10	1	5' - 0"	10 "	2.0	0.20	3.0
10	2	10' - 0"	10 "	2.0	0.20	3.0
11	1	5' - 0"	10 "	2.0	0.20	3.0
11	2	10' - 0"	10 "	1.0	0.10	1.5
11	3	12' - 0"	15 "	1.0	0.07	1.5
12	1	5' - 0"	15 "	3.0	0.20	4.5
12	2	10' - 0"	5 "	0.3	0.06	0.5
12	3	15' - 0"	15 "	3.0	0.20	4.5
12	4	19' - 5"	15 "	6.0	0.40	9.0
13	1	5' - 0"	5 "	2.0	0.40	3.0
13	2	9' - 0"	5 "	0.2	0.04	0.3
13	3	10' - 0"	5 "	2.0	0.40	3.0
13	4	16' - 0"	5 "	0.6	0.12	0.9
14	1	5' - 0"	15 "	3.0	0.20	4.5
14	2	11' - 0"	15 "	6.0	0.40	9.0
14	3	13' - 0"	15 "	3.0	0.20	4.5

Sludge Samples Cont'd.

Hole No.	Sample Number	Sample Depth	Sample Size	Net Cts/ minute	Cts/Min/ ml	$\sim 10^{-5}$ $\mu c/gm$
17	1	5' - 0"	5 ml	1.0	0.20	1.5
17	5A	5' - 0"	15 "	6.0	0.40	9.0
18	1	5' - 0"	15 "	0.0	0.00	0.0
18	1A	11' - 0"	15 "	3.0	0.20	4.5
24	1	5' - 0"	10 "	1.0	0.10	1.5
25	1	5' - 0"	15 "	1.0	0.07	1.5
25	2	10' - 0"	10 "	0.0	0.00	0.0
26	1	5' - 0"	15 "	6.0	0.40	9.0
27	1	0' - 6"	5 "	1.0	0.20	1.5
27	2	5' - 0"	5 "	2.0	0.40	3.0
28	1	5' - 0"	15 "	8.0	0.53	12.0
28	2	10' - 0"	10 "	1.0	0.10	1.5
28	3	15' - 0"	10 "	2.0	0.20	3.0
29	1	5' - 0"	5 "	1.0	0.20	1.5
29	2	10' - 0"	5 "	0.0	0.00	0.0
30	1	5' - 0"	15 "	3.0	0.20	4.5
35	1	5' - 0"	5 "	2.0	0.40	3.0
37	1	5' - 0"	5 "	1.0	0.20	1.5
38	1	5' - 0"	5 "	1.0	0.20	1.5
38	2	10' - 0"	5 "	2.0	0.40	3.0
38	3	15' - 0"	5 "	11.0	2.20	16.5
38	4	20' - 0"	5 "	4.0	0.80	6.0
39	1	10' - 0"	5 "	1.0	0.20	1.5
50	1	5' - 0"	10 "	1.0	0.10	1.5
50	2	10' - 0"	10 "	1.0	0.10	1.5

B. Water Samples

Hole No.	Sample Size	Net/cts/min.	Cts/min/ml	$\mu c/cc \times 10^{-7}$
1	5 ml	1.4	0.28	12.6
1	10 "	1.0	0.10	4.5
1	5 "	0.0	0.00	0.0
2	200 "	4.0	0.02	0.9
2	10 "	0.0	0.00	0.0
3	10 "	1.0	0.10	4.5
4	20 "	3.0	0.15	6.7
4	20 "	2.0	0.10	4.5
5	10 "	0.0	0.00	0.0
6	10 "	0.0	0.00	0.0
7	5 "	0.0	0.00	0.0
8	10 "	4.0	0.40	18.2
9	10 "	0.0	0.00	0.0
10	10 "	2.0	0.20	9.1
11	15 "	1.0	0.07	3.2
12	15 "	6.0	0.40	18.2
13	15 "	4.0	0.26	11.7
14	15 "	2.0	0.13	5.8
15	10 "	0.0	0.00	0.0
16	15 "	1.0	0.07	3.2
17	15 "	6.0	0.40	18.2
18	15 "	0.0	0.00	0.0
20	15 "	0.0	0.00	0.0
21	15 "	1.0	0.07	3.2
22	15 "	7.0	0.46	20.7
23	10 "	2.0	0.20	9.1
24	10 "	1.0	0.10	4.5

Hole No.	Sample Size	Net/cts/min.	Cts/min/ml	$\mu c/cc \times 10^{-7}$
26	10 ml	2.0	0.20	9.1
27	15 "	3.0	0.20	9.1
28	10 "	1.0	0.10	4.5
29	15 "	1.0	0.07	3.2
30	10 "	2.0	0.20	9.1
31	10 "	2.0	0.20	9.1
32	15 "	1.0	0.07	3.2
33	10 "	1.0	0.10	4.5
34	15 "	7.0	0.46	20.7
35	10 "	2.0	0.20	9.1
36	10 "	4.0	0.40	18.2
37	15 "	8.0	0.53	23.8
38	15 "	2.0	0.13	5.8
39	10 "	1.0	0.10	4.5
40	10 "	4.0	0.40	18.2
42	10 "	3.0	0.30	13.6
43	10 "	0.0	0.00	0.0
44	15 "	0.0	0.00	0.0
45	10 "	0.0	0.00	0.0
46	10 "	0.0	0.00	0.0
47	10 "	0.0	0.00	0.0
49	10 "	1.0	0.10	4.5

Table 5--Radiation Detected by Radiologging, Expressed in Counts per Minute

Depth from Ground Surface in Feet	Well # 1	2	3	4	5	6	7	8	9	10	11	12	13	14	17	18	19	26	27	28	29	30	32	33	34	35	36	38	39	40	50	Average
3	32	32	56	41	80*	38	58	48		36	40	52	42	55	72*	36	35	64*	56	52*	75*	40	60	30	30	160*	75*	51	60	46	85*	60
6	27	36	52*	33	100*	37	54*	46		35	37	48	42	53*	72*	34	60*	33	125*	62*	40	33	40	32	75*	50*	75*	50	70*	66*	97*	50
8	24	25	49*	29	60*	38	48*	32		37	33	35	40	52*	125*	29	52*	32	33	58*	65*	21	45	36	20	50*	50*	48*	65*	62*	105*	45
9	24	21	48*	29	60*	37	45*	29		40	29	25	38	51*	195*	28	48*	30	26	48*	75*	23	40	39*	26	50*	60*	46	55*	70*	127*	48
14	18	18	40*	20	65*	20	28	27		30	22	23	37*	35	70*	28	35	20	27	35	80*	32	25	28	20	50*	75*	46*	50*	60*	125*	38
20	24	19	30	19	35*	14	17	23		29	26	24	37*	21	83*	26	35	34	38*	27	86*	29	20	53*	20	40*	45*	57*	major cave in at 17 ft	50*	90*	35
22	22	21	30	17	25	14	17	27		27	26	24	30	20	83*	29	35*	36*	29	22	60*	26	26	49*	10	40*	50*	58*		43*	95*	34
27	20	18	30*	20	80*	15	15	24		23	25	25	9	26	79*	28	44*	25	25	24	110*	23	20	32*	28		45*	24		24	100*	30
29	19	18	30*	20	75*	10	15	24		23	23	25	30	21	79*	22	38*	25	24	24	110*	30	20	40*	30		10	30		20	98*	30
33	33	14	30*	20	35*	14	14	34*		32*	22	29	22	23	70*	25	35*	36*	31*	30*	80*	29	0	38*	30		15	22		24	98*	31
38	26	14	29*	19	35*	12	16	29*		25	20	25	24	26	78*	16	34*	41*	23	54*	95*	19	30*	25	30*		15	25		20	90*	29
45	22	19	24	19	35*	13	23	25		15	14	23	29*	26	90*	14	27		29*	42*	90*	12	25	13	20		16			18	95*	28
52	24	19	19	21	35*	14	17	23		10	25	24	28	27	87*	10	25			46*	76*		25				10				85*	29
58	20	19	23	20	35*	16	16	21		8	23	27	26	22	92*	11	29*			37*	25*		25								80*	28
60	30*	20	10	20	25	14	12	14*		8	24	25	26	18	95*	12	32*			16	15		25								72*	28
62	26	17	10	21	25	15	12	13		8	23	25	26	20	95*	12	30*			47*	10		30*								72*	27
65	35*	19	13	20	40*	13	16	13		9	23	25	28*	21	82*	12	25			35*	10		25								73*	26
75	26*	16	10	19	20	23	28*	10		12	30*	16	19	19	60*	12	29*			19	5		10								39*	24
79	29*	18	13	21	20	23	30*	10		11	27*	22	18	16	63*	12	27*			36	10		15								28*	24
87	36*	26*	12	16	17	24*	23*	12		13	20	20	22	14	50*	10	29*			34*	15		5								20*	22
95	15	22*	15	26*	16	20	24*	13		14	25*	23*	16	15	50*	10	23*			34*	5		8									22
99	11	22*	15	25*	8	50*	29*	11		15	21	24*	20		25000*	14	28*			38*	5		10									22
100	11	20*	14	25*	16		20*	10		21*		24*									5		10									18
102	12		14		17*																10		10									13
105	13		13																		80*											13
135	9		26*																													18
225	23*		15																													
244	49*																															

* Indicates measured activity exceeds the average of other wells, at the corresponding depth.